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LUNAR BASES AND SPACE ACTIVITIES OF THE 21st CENTURY

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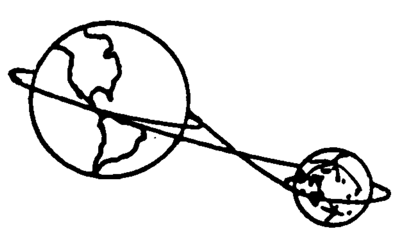
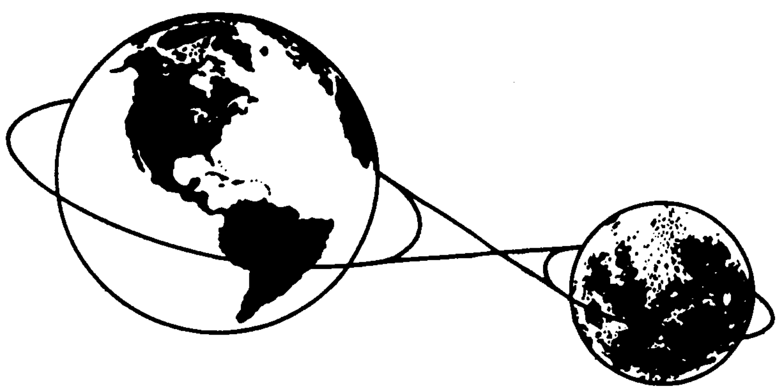


LUNAR BASES AND SPACE ACTIVITIES IN THE 21st CENTURY

A SYMPOSIUM
October 29-31, 1984



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PREFACE

This volume contains abstracts that have been accepted by the Program Committee for presentation at the Symposium "Lunar Bases and Space Activities of the 21st Century," held in Washington, D.C., October 29-31, 1984. The members of the program committee are listed below:

Michael B. Duke(Chairman), NASA Johnson Space Center
Larry Haskin, Washington University
Paul W. Keaton, Los Alamos National Laboratory
Robert H. Manka, National Research Council
Wendell W. Mendell, NASA Johnson Space Center
Barney B. Roberts, NASA Johnson Space Center
Harlan J. Smith, University of Texas
G. Jeffrey Taylor, University of New Mexico
Richard Thomas, Texas A&M University
Stanley Weiss, Lockheed Corporation

This volume was prepared by the Solar System Exploration Division, Johnson Space Center, National Aeronautics and Space Administration.

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LUNAR BASES AND SPACE ACTIVITIES OF THE 21ST CENTURY

FOREWORD

The origin of this symposium lies in the resurgence of the space program of the United States. The initiation of routine flights of the Space Shuttle to and from space is rapidly expanding operational capability there, and the President's commitment to developing the Space Station makes more certain that the development of the space infrastructure will continue in the foreseeable future. Prior to this time it was difficult to seriously address programs such as lunar bases because there was no delivery system capable of launching the necessary materials to Earth orbit or move them to the lunar surface. Now, the basis of the system necessary to emplace men and materials on the Moon routinely can be foreseen. The Shuttle is operational. The Space Station and Orbital Transfer Vehicles, which will be a part of the Earth orbit capability, will make the vicinity of the Moon just as accessible as Geosynchronous orbit. It is time to address those longer term issues that can guide the development of the space infrastructure over the next 15 to 25 years. Consideration of lunar bases is, therefore, timely.

It is also necessary to search for those longer term goals that can energize our Nation and the younger generation who will carry them out - goals which are difficult, yet feasible, which demand education, innovation, dedication and excellence in all aspects of science, technology, and human relations. The lunar base and the potential for permanent human inhabitation of the planets is such a goal.

The program follows a workshop held in April, 1984, at the Los Alamos Branch of the University of California's Institute for Geophysics and Planetary Physics. At that workshop, the range of activities that might be carried out at a lunar base was explored, and some of the technological and social implications identified. This symposium provides an opportunity for the broad range of people who are interested in lunar bases or other space activities beyond the Space Station to meet, exchange ideas, and perhaps nucleate a program that will lead us to the Moon and beyond.

Michael B. Duke
Johnson Space Center
Houston, Texas 77058

September 26, 1984

ABSTRACTS OF THE SYMPOSIUM

LUNAR BASES AND SPACE ACTIVITIES OF THE 21ST CENTURY

GROUP MEETING IIA - PLASMA AND PARTICLE OBSERVATIONS

GROUP MEETING IIB - LUNAR BASE SCENARIOS AND THE SPACE TRANSPORTATION SYSTEM

GROUP MEETING IIC - STRATEGIES FOR PLANETARY EXPLORATION

PLENARY III - SCIENCE OPPORTUNITIES

GROUP MEETING IIIA - LUNAR CONSTRUCTION

GROUP IVC - RESOURCES: EXTRACTION AND MANUFACTURING TECHNOLOGIES

PLENARY V - TRANSPORTATION AND LUNAR BASE SCENARIOS

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THE LUNAR BASE ADVOCACY. Wendell W. Mendell, NASA Johnson Space Center, Houston, TX 77058

Examination of the U.S. space program shows that NASA is constructing a civilian space transportation system which will give this nation a renewed space-faring capability. The capacity and scale of the total enterprise is uncertain because the long term requirements are not well defined. However, by the mid-1990's, systems will be on the drawing boards having the capacity to place humans in geosynchronous orbit (GEO) and the energetically equivalent lunar orbit.

Under those circumstances, a lunar base undoubtedly will come to the fore as a space policy objective for the first decade of the 21st Century. Historically, the Moon has been a target for every major advance in space capability. The lunar surface again will be viewed in the context of the newest plateau of achievement, permanent human presence as expressed by the low Earth orbit Space Station.

Since establishment of the first human community on another planet could be a cultural event of significant magnitude, careful consideration of the long-range strategy for lunar occupation is very important. Yet, it is also part of the historical record that major decisions regarding new space initiatives can be made quickly in time of political crisis, either domestic or international. Thus, the lunar option and its implications must be studied now while the space transportation system is still being conceived. This symposium is part of a process intended to crystallize that activity.

One overview of a long range lunar program breaks it into five phases, ranging from Precursor Exploration to a Self-sufficient Colony.[1] Activities in the first phase, preceding the actual political commitment, include collection of key scientific data about the Moon, evaluation of potential lunar-based technologies and resources, keeping the lunar option open as the space transportation system evolves, and consideration of the implications of a lunar base for national policy - scientific, technological, economic, geopolitical, and social. The papers presented here touch on all elements of this astoundingly diverse range of issues.

Much information required to support the postulated decision process can be developed within ongoing NASA programs, but some redirection and some reprogramming is required. Neither is simple in the competition for limited resources. The role of lunar base advocacy within NASA is clear demonstration of relevance to the agency's mission and presentation of a technically sound, fiscally responsible approach to objectives. Since formulation of space policy is ultimately a public endeavor, advocacy external to NASA is also essential in the context of national priorities. This conference must arrive at mechanisms for continuation of effective advocacy.

A manned lunar base is a complex subject which extends beyond the purely technological component. Considering that no lunar program now exists, the breadth and depth of the contributed papers here is a measure of the underlying excitement inherent in the idea. Nevertheless the principal question is whether we are practicing a form of visionary self-delusion or whether real progress can be made toward a fair hearing by the political process. I personally believe that hearing is possible; but the advocacy must be responsible, pragmatic, and professional while maintaining vision, enthusiasm and self-motivation.

Reference:

1. Duke, Michael B., Wendell W. Mendell, and Barney B. Roberts (1984) Toward a Lunar Base Program. (preprint)

THE LUNAR BASE SITE SELECTION AND SCIENCE. Harold Masursky, USGS, Flagstaff, AZ and P. D. Spudis, USGS, Flagstaff, AZ and Arizona State Univ., Tempe, AZ

Throughout the course of lunar investigations, site selection has always provided an accurate assessment of the then prevailing state of lunar knowledge. The state of knowledge at any particular period has shaped site selection efforts, from the earliest period of ground-base telescopic studies, through the Apollo precursor missions (Ranger, Surveyor, and Lunar Orbiter) and the Apollo missions, to the present time when proposals for a Lunar Polar Orbiter mission and future establishment of a lunar base are in progress. In the early pre-Apollo period of study, intense debates were held concerning whether the Moon is "cold" and has been affected solely by the impact process, or whether it is "hot" and has also been affected by volcanic processes. If the "cold" Moon thesis were correct only one sample of the homogeneous Moon would be needed to complete its exploration. When the Surveyor lander analyzed the lunar rocks and reported that they appeared to be basaltic in composition, Harold Urey, one of our patron saints but a "cold Moon" advocate, said that "if they do that again, I'm in trouble". They did and he was. We later chose Apollo landing sites on the basis of our perception that a variety of geologic processes had affected the lunar crust. However, limitations on descent profiles, lunar heterogeneity, and the difficulty of establishing telecommunication links drastically limited the choice of available areas that could be investigated by Apollo. The choice of landing sites available to the Soviet automated sample-return spacecraft was even more limited. The currently proposed global geochemical-geophysical orbiter will allow us to make a better choice for a future lunar base. With information from this mission, a base can be located anywhere on the Moon that satisfies scientific, engineering, and technological requirements. In addition to other scientific goals, we also can design local and regional exploration studies that will address many unanswered scientific questions. Examples of such studies include: 1) mechanics of crater and large-basin formation, including the thickness and extent of ejecta deposits, the abundance of local versus far-traveled ejecta, and the effects of clustered ejecta impacts; 2) the origin of the highland crust -- from a magma "ocean", or by serial emplacement of magmatic and volcanic rocks; 3) the composition, origin, and time of emplacement of mare materials, which may range from 4.3 to 1.0 billion years in age; 4) the origin and age of light plains materials. As we find answers to questions that have been asked from the beginning of lunar studies, we can ask more sophisticated question that probe more deeply into fundamental planetary processes.

LUNAR STATIONS: THE PROSPECTS FOR INTERNATIONAL COOPERATION

Dr. Philip M. Smith
National Academy of Science
Washington DC 20418

ABSTRACT NOT RECEIVED IN TIME FOR INCLUSION

A MILLENNIUM PROJECT: MARS 2000

Harrison H. Schmitt, Consultant, P.O. Box 8261, Albuquerque, NM

The frontier of space, the new ocean of exploration, commerce and human achievement, has produced a level of excitement and motivation among the young generations of the world that has not been seen for nearly a century. History clearly shows us that nothing motivates the young in spirit like a frontier. The exploration and settlement of the space frontier is going to occupy the creative thoughts and energies of generations for the indefinite future. The only principal historical issues in doubt are the roles that will be played by free men and women and how those roles will relate to the problems of the human condition here on earth.

The return of Americans to deep space must be viewed in the context of the nation's over-all perspective of its role in the future of human kind. Although that role in space has not been fully formulated into a national consensus, it seems safe to say that for generations now alive it can be viewed as interweaving the on-going Age of Information, the soon-to-be Earth Orbital Civilization and the world's possible Millennium Project: Mars 2000.

UNMANNED SPACEFLIGHTS NEEDED AS SCIENTIFIC PREPARATION FOR A MANNED LUNAR BASE. Don E. Wilhelms, U.S. Geological Survey, Menlo Park, CA 94025

Despite the technological and scientific successes of lunar exploration, much remains to be learned about lunar origin, subsurface structure, composition, mare and terra petrogenesis, history before 3.85 aeons ago (Imbrium basin), history after 3.2 aeons ago (Apollo 12 mare), and even such fundamental quantities as topography and the offset of the center of mass. Good photographs cover less of the Moon than of Mars. Therefore, a future lunar base can be neither effectively sited nor productively exploited scientifically without additional preparatory exploration by unmanned spaceflights. Global orbiters and targeted landers are both needed.

Near-polar orbiters could gather important data concerning (1) topography, especially in and near basins; (2) the gravity fields of the Moon and of basins; (3) mare compositions; (4) terra compositions, an even more serious gap; (5) the puzzling problem of magnetism; and (6) the stratigraphy of poorly photographed regions, particularly the regions poleward of 40° N. and S. latitudes, a zone along longitude 100-120° W., and the east limb on both the near and far hemispheres. Knowledge of the Moon's third dimension could be greatly improved by this orbital exploration.

Other problems require additional samples from the Moon itself. The table below recommends some landing sites of unmanned sample-return spacecraft which could provide important geologic data. Each probe is considered capable of returning a single sample of regolith randomly selected from within the designated area. Objectives fall into five main categories: (1) absolute ages needed to calibrate the stratigraphic column and therefore the impact rate and thermal history, (2) compositions and textures for deciding such genetic problems as the hypothetical terra volcanism, (3) crustal compositions at points of known stratigraphic context which can be extrapolated to larger areas, (4) mantle compositions inferable from samples of currently unsampled color- and age units of mare basalt, and (5) ancient volcanic basalts. Data from most of the selected targets can be extrapolated by means of currently available or future orbital sensing. An additional requirement, not specifically addressed here, is for new seismic data to determine crustal thickness and other poorly known properties of the interior.

	Target	Principal problems
1.	Nectaris-basin impact melt----------	Age; crustal composition.
2.	Copernican mare SE of Lichtenberg---	Age; composition.
3.	Terra plains------------------------	Nonmare volcanism or buried mare?
4.	Terra domes-------------------------	Nonmare volcanism?
5.	Farside mare------------------------	Composition of source.
6.	Orientale-basin impact melt---------	Age; crustal composition.
7.	Copernicus impact melt (floor)------	Age; crustal composition.
8.	King impact melt (floor)------------	Farside crustal composition; age.
9.	Ancient crust near 30° N., 160° E.--	Composition; age.
10.	"Big Backside Basin" massifs--------	Crustal composition; age.
11.	Pre-Late Imbrian mare basalt--------	Age; composition.
12.	Old (KREEPy?) mare basalt-----------	Age; composition.
13.	Eratosthenian mare------------------	Age; calibrate color spectra.
14.	Central Mare Serenitatis------------	Calibrate color spectra.

LUNAR FIELD GEOLOGY AND THE LUNAR BASE. P.D. Spudis, USGS/Flagstaff, AZ and Dept. of Geol., ASU/Tempe, AZ

The study of the geologic history of planetary bodies proceeds from the general to the specific. This process has been dictated largely by the means of geologic exploration imposed by spacecraft whereby photoanalysis of global geologic relations is the first step in formulating planetary geologic history. Subsequent surface exploration provides "ground truth" for the inferences obtained by remote-sensing. Now that we are moving beyond the reconnaissance phase of lunar exploration, field geology has an important role. Field geology on the Moon differs only in practice, not in principle, from terrestrial field geology; it provides key information that may be the difference between correct understanding of the geologic history of a given region and wholly erroneous conclusions that may be drawn with geologically uncontrolled data.

Experience gathered from the Apollo field geology experiment indicates several possible pitfalls. Proper field technique during Apollo was inhibited by strict mission planning. Because of limited life-support capabilities, geologic traverses had to be carefully planned in advance, with time allocated to specific tasks at specific stations. Such strict planning inevitably provided dilemmas; the decision to extend the time spent at the South Massif on Apollo 17 EVA-2 lessened the time available to sample Shorty crater. This is not to say the decision was wrong, only that the constraints imposed by the Apollo system prevented adequate time to do proper field geology. A similar experience during Apollo 15 prevented the crew from visiting the North Complex when it was decided that the deep-drill core was more important than another field geology station.

Although the time problem will be alleviated at a lunar base, it will not be totally eliminated. Thus we should carefully consider the philosophy of lunar field geology so as to maximize the scientific return. Field geology is essentially an iterative process; although a generalized plan is formulated prior to field work, this plan must be flexible enough to be modified in real time in response to changing concepts of what observations mean. Revisiting previously examined outcrops is a technique unheard of during Apollo, yet it is frequently done on Earth both to supplement new knowledge and to modify the existing (and evolving) conceptual framework. The best judge of what is geologically significant in the field is the field geologist, who has wrestled with the complexities of rocks in their natural state. For this reason, the strict timelines and guidance of Earth-based support teams of Apollo are undesirable for lunar base operations; they are counterproductive to the making of significant scientific discoveries.

Although careful planning must preceed the field traverses, the geologist on the Moon should be given maximum freedom to pursue those objectives that appear at the time to be most interesting. Most importantly, block allocations of time should be programmed into the schedule to provide the all-important "think and synthesize" sessions that invariably produce the most results in terrestrial field geology. Although this seems like a waste of time, it is not; it is a maximization of efficiency to collect, for example, two geologically significant samples rather than a dozen random ones. A technological development that would greatly facilitate the type of exploration advocated here would be a roving, self-contained traverse vehicle, with first-order geochemical analytic capability. Such a vehicle would enable extended manned geologic exploration that would maximize the use of the human element in our continuing drive to decipher the history of the Moon.

A GEOLOGICAL TRAVERSE ACROSS THE IMBRIUM BASIN REGION. P.D. Spudis, USGS/Flagstaff, AZ and Arizona State Univ., Tempe, AZ; M.J. Cintala, NASA/JSC, Houston, TX; B.R. Hawke, HIG/Univ. Hawaii, Honolulu, HI

A manned geological traverse across the Imbrium basin region has the potential to answer first-order questions about lunar geologic processes and the evolution of the Moon. We present a plan of exploration that would address several major, unresolved scientific questions about the Moon (Figure 1 shows the suggested traverse route with station stops). Three principal scientific topics will be addressed. (1) Processes of multi-ring basin formation will be studied by radial and concentric observations and sampling of Imbrium basin structures and deposits (Stations 1, 2, 4-6, 10, 16, 19, 21, 23, 28). Additionally, geophysical profiling across the basin will enable the determination of subsurface structure and stratigraphy (Sta. 1-26). (2) Processes of large crater formation will be studied by radial sampling and drilling of the large craters Conon, Erathosthenes, Copernicus, and Aristarchus (Sta. 4, 10-16, 22-25). Among the processes to be examined are: a) primary ejecta fractions in crater continuous and discontinuous facies; b) melt sheet and central peak formation; and c) crater subsurface structure. (3) Lunar volcanic processes will be studied by sampling a diverse suite of volcanic units, including the most recent maria (Sta. 20, 26, 22), early Imbrian non-mare KREEP volcanic units (Sta. 7) and spectrally distinct regions that may represent exotic lunar rock types (Sta. 8, 19, 21, 25). The total traverse distance is approximately 4000 km; it is anticipated that a scientific team of 4-6 would take about 3 to 6 months to complete the work. Geological field work would be facilitated by a self-contained traverse vehicle with first-order chemical/petrologic analytical equipment and high-resolution remote-sensing support; field equipment should include a deep-drilling (i.e., hundreds of meters) rig with coring capabilities. Such an exploration plan would provide an abundance of data directly applicable to the primary questions of lunar geology that remain unanswered by Apollo exploration.

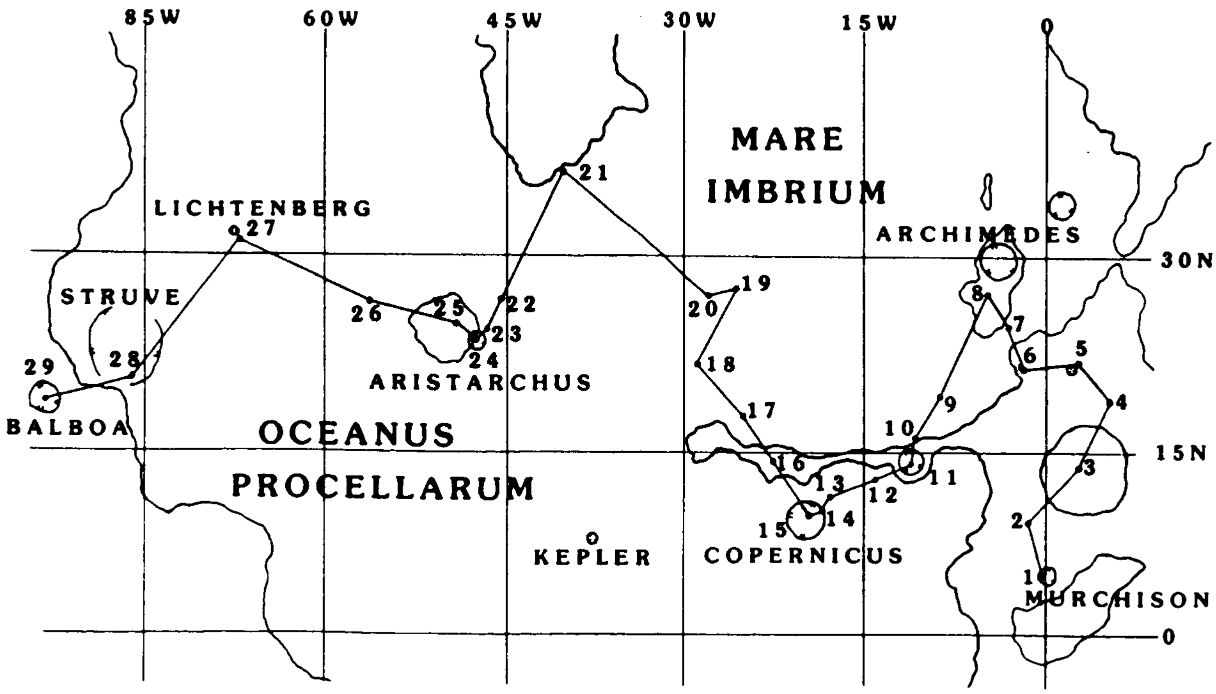

Figure 1. Suggested traverse route and stops.

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A SEARCH FOR ANCIENT BURIED LUNAR SOILS AT A LUNAR BASE

David S. McKay, Mail Code SN4, NASA Johnson Space Center
Houston TX 77058

The search for old lunar regolith is an important part of lunar scientific investigations. Much of the analysis of lunar cores was directed at finding old lunar soil samples. Part of the current lunar regolith initiative is directed at studies of lunar regolith breccias in the hope that some of them may be made of ancient regolith which has preserved a record of the conditions under which it was originally exposed as soil on the surface of the moon. Ancient lunar regolith may preserve a record of the sun dating back billions of years ago. It may contain solar wind and radiation damage features dating from very early times. Some evidence exists that isotopic ratios of some solar wind species have varied considerably over time. A possibility exists that the luminosity of the sun was significantly different billions of years ago compared to the present value. Variations of this sort may have had an effect on the geologic evolution of the earth or even on the evolution of life. Additionally, the ancient lunar regolith may also preserve a record of the volcanic history of the young moon. Volatiles from ancient lunar volcanos may be preserved. A chemical record of early impacting objects may also be preserved.

A problem with current searches for ancient lunar regolith is that it is very difficult to determine the time at which a collected regolith sample was actually exposed at the lunar surface and the time at which it was buried and closed to exposure effects. Such times must be determined indirectly or only inferred for core samples and for regolith breccia samples. The ideal case would be a zone of lunar regolith which was exposed at the lunar surface at a time in the past which could be accurately determined, was exposed for a known length of time, and was then covered and completely isolated from further exposure at a time which could be accurately determined. We do not have samples which approach this ideal but such samples may exist and may be easily accessible at a lunar base. All of the criteria for an ideal sample would be met by a zone of lunar regolith sandwiched between two basalt flows. The first exposure time could be accurately dated by the radiometrically determined age of the bottom flow. The burial or closure time would be accurately determined by the age of the upper flow. The exposure interval would simply be the difference in ages of the two flows. Confidence that the regolith zone had remained buried would come from stratigraphic and structural relationships as seen in a trench or mining cut.

While some parts of this ancient regolith may have been disturbed by younger impacts, statistical considerations would argue that some of it would be preserved undisturbed and the undisturbed parts should be easily identifiable in a trench or mining cut. Detailed analysis of this ancient regolith would reveal much about conditions in the early solar system. It is possible that numerous regolith zones may exist between basalt flows ranging over a relatively long time span. Thus the possibility exists that a number of 'snapshots' of conditions in early solar system over a period of time are preserved. Such samples could be also sought at a lunar base by drilling through basalt flows or by examining the walls of craters which had penetrated through several basalt flows alothough care must be taken to avoid material having recent exposure. The pre-lava regolith beneath all of the basalt might also be accessible at appropriate craters or by deep drilling.

STRATIGRAPHIC MAPPING AND SAMPLING AT A LUNAR BASE FOR GEOCHEMICAL AND PETROLOGIC STUDY. Larry A. Haskin, Department of Earth and Planetary Sciences, Washington University, St. Louis, Missouri 63130.

Apollo samples reveal much about the Moon. Further sampling, in stratigraphic context, is fundamental to learning the order of formation of the Moon's deep crustal rocks, the compositional sequence of its lava flows, how its deep and shallow regolith formed, and other first-order aspects of its history.

Attempts to establish stratigraphic relationships among Apollo samples have relied on anticipated patterns for crater ejecta and matching general appearance of samples to blocks seen within craters, often from photographs. Consider North Ray Crater, 1 km in diameter and 230 m deep, Descartes Highlands, Apollo 16. Duke and Young (1) collected >30 breccias from the southern rim and provided comments and photography of the northern wall. Ulrich (2) matched the light or dark breccias with light and dark materials on the crater wall or obscuring talus. He believed the crater penetrated Imbrium ejecta overlain by Orientale ejecta.

Geochemical and petrographic studies (e.g., 3,4) found many rock types among the breccias. Dark material includes 3 to 5 types of melt rocks, light material 3 types of granulite, anorthosite, and very KREEP-rich and KREEP-poor materials, suggesting complex layering of the strata excavated. Apollo 16 rocks are unlike those of Apollos 15 and 17 and are the closest to "typical" lunar highlands materials (5), so implications are Moon-wide.

A lunar base will have teleoperated dirt-moving equipment to excavate and cover habitation modules. A device of even modest capacity, 10 m^3/hour, could cut a trench 10 m wide by 2 m deep from the rim to the floor of North Ray Crater in one lunar day's time. Two to 4 such sections would reveal the stratigraphy at the crater site. The amount of dirt to be moved is uncertain but within geographic and logistical capability for a base at the Apollo 16 site. The exposed wall could be extensively sampled, preliminary examination of rocks and thin sections done at the base, a selected suite sent to Earth for detailed study, and implications for distant or local sources established.

Also crucial are stratigraphic relations among early crustal igneous rocks. That stratigraphy has been disrupted if not obliterated by crater-forming impacts. Substantial chunks may be intact, and a possible example is Silver Spur, a tilted, layered block 800 m high, observed 20 km from the Apollo 15 site, by Irwin and Scott (6). Breccias from the Apennine front seem to be first generation, one type of melt rock plus fragments of coarse-grained igneous rocks (7,8). Sampling and mapping the face of Silver Spur and the wall of Hadley Rille could be done from a winch-driven sling on a simple rover.

These are two examples of valuable experiments using relatively simple equipment within a short distance from a lunar base.

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THE EARLY GEOCHEMICAL EVOLUTION OF PLANETARY CRUSTS: A DETAILED STUDY OF THE CRUSTAL EVOLUTION OF THE MOON FROM A LUNAR BASE.

G.W. Lugmair, Scripps Inst. of Oceanography and Chemistry Dept., UCSD, La Jolla, CA 92093

Unlike the Earth, the Moon is a planetary body whose chemical and geologic evolution became frozen in time and at a stage about which little, if anything, is known for the earth. The oldest remaining pieces of the earth's crust, which survived reworking during aeons of geologic activity, date back to "only" 3.8 billion years before the present. This is about the time when the large basins were excavated on the front side of the moon by impacts of small planetesimals several kilometers in size. Gigantic amounts of basaltic lava extruded from the lunar interior to fill these impact structures which we call Lunar Maria. These can easily be distinguished from earth with the unaided eye as the dark areas. The lighter regions are what we call the lunar highlands or crust. They cover the major portion of the lunar surface and are the result of the global chemical and geologic evolution during the first approximately 500 million years of a major planetary body. Presumably, a similar process occurred on the earth, but basically nothing has survived from that early age and it will be very difficult, and probably impossible, to reconstruct the evolutionary history of earth's infancy from terrestrial studies. In other words, a detailed study of lunar crustal evolution will not only permit us to acquire important knowledge about the moon; it will yield invaluable information on the earth's shrouded past and, in general, about the mechanisms involved in early planetary differentiation.

From studies over the past 15 years of samples returned from the moon by Apollo spacecraft, we have gained a vast amount of knowledge with regard to the moon's time of formation ($\sim$4.5 billion years ago), its overall chemical composition, and the time when the large basins formed. With new and refined analytical techniques, we have obtained detailed information on questions such as the time of formation of various lunar rock types and likely mechanisms responsible for their production. Considering the very limited sampling of a whole planet, an amazingly coherent picture has emerged about the moon. More pieces are added to the puzzle as hitherto unexamined samples are being studied or previously analyzed samples are reexamined by more sophisticated techniques. Still, with regard to sampling of a whole planet, the sample collection is extremely limited and, from a field geologic point of view, rather superficial.

It is clear that a proper sampling, even of only key regions at first, necessitates a permanent or at least long term presence of man on the moon. Regions for study may be selected on the basis of high resolution orbital chemical analyses. Short to at least medium range transportation will be required with a vehicle which will be capable of supporting an extended stay of scientists in the field. A detailed sampling of bedrock which may, for example, be exposed at the walls of major impact craters could be performed. A permanent Lunar Base will afford easy access to the same site for resampling after preliminary examinations at the Base or more detailed studies on earth have been carried out. The analytical facilities at the Lunar Base should at least include instrumentation for X-ray diffraction analysis, electron microscopy with energy dispersive X-ray analyzer with all the necessary sample preparation equipment, and optical microscopy. It would be highly desirable to include also facilities for trace element analysis such as ICP. In the longer range some of the analytical instrumentation may even be installed on board the exploration vehicle in a miniaturized form for preliminary examination in the field which would facilitate immediate feedback of analytical data during sample collection and mapping.

INVESTIGATIONS OF LUNAR HIGHLANDS IGNEOUS ROCKS AND METAMORPHIC PROCESSES.
Marilyn M. Lindstrom, Department of Earth and Planetary Sciences, Washington University, St. Louis, Missouri 63130.

Most lunar highlands samples are breccias, the products of the extensive impact history of the lunar crust. However, a small proportion of returned lunar samples is plutonic igneous rocks, which are brecciated, shocked and metamorphosed to various degrees and found as discrete rocks or included as clasts in breccias. An even smaller proportion of highland rocks is volcanic rocks, KREEP basalts and high-Al mare basalts. These plutonic and volcanic igneous rocks are the products of lunar differentiation and are crucial for understanding lunar evolution.

Metamorphism is an important process in lunar plutonic rocks and although impacts may be the major driving force, the details of the metamorphic process are not well understood. The nature of fluids that percolate through the system and the compositional and mineral changes that occur in samples which are heated and subjected to moderate pressures, but not melted, are unknown. Observations on returned lunar samples are tantalizing. Evidence of enrichment processes, perhaps similar to terrestrial ore-forming processes, are seen in the most meta-morphosed plutonic rocks. In Apollo 16 breccia 67016, anorthositic norites occur with both cumulate and metamorphic textures. The metamorphosed samples contain veins of Fe-sulfides and areas which are peppered with sulfide blebs where silicates reacted with sulfur-rich gas. Some metamorphosed plutonic rocks, both magnesian and alkali anorthosites in Apollo 14 breccia 14321 and alkali gabbronorite in Apollo 16 breccia 67975, are rich in phosphates having extraordinary high levels of REE. The origin of these phosphates is unknown, but simple igneous processes cannot generate all of the rocks and both assimilation of KREEP and alteration by metasomatic fluids are possible processes.

Rocks of KREEP composition are themselves enigmatic. They are abundant at Apollo 14 but occur there only as complex impact melt breccias. The Apollo 15 KREEP basalts, which appear to be true volcanic rocks, are rare and less concentrated in REE than the Apollo 14 breccias. The nature of KREEP and relationship to REE-rich plutonic rocks is another important question in lunar crustal evolution.

The return to the Moon and establishment of lunar base is a prime opportunity for the geologic study of lunar highland rocks. Since most of the highlands rocks are breccias it is impossible to say just where to go to find a specific type of lunar plutonic rock or to study metamorphic processes. Ideally we would like to study samples both from typical lunar highlands (central or farside highlands) and from atypical highlands around Mare Imbrium where KREEP-rich samples are abundant. The Apollo 15 site provides an excellent example for sampling both lunar plutonic rocks and KREEP-rich volcanic rocks. The samples collected from the base of the Apennine Front are relatively simple breccias composed of highland rocks of KREEP (15405) and plutonic (15445 and 15455) affinities. The clasts are somewhat metamorphosed, but do not appear to have undergone numerous impacts as do the samples from Apollo 14 and 16 sites. In addition, we may have an opportunity to sample bedrock at Silver Spur, an uplifted block of the Apennine Front, which has many layers of highland rocks visible on its face.

We suggest studying lunar plutonic rocks, metamorphic processes and KREEP basalts in a geologic investigation of the Apennine Front at the Apollo 15 site. From a lunar base, presumably in the mare basin, we would approach the Apennine Front while mapping and collecting samples of bedrock or large boulders. A detailed study of samples from Silver Spur would be a primary goal, but other studies would depend upon what was encountered. Sampling should include any large areas of plutonic rocks, the white to gray clasts in the dark melt rock matrix of the breccias and any highland basalt units observed. A unit where rocks show varying degrees of metamorphism should be sought so that the effects of metamorphism on plutonic rocks could be evaluated. After careful mapping, samples would be collected and returned to the base for preliminary examination based on thin section and possibly X-ray fluorescence studies. A selected suite of highland samples would be returned to Earth for more detailed petrographic and compositional studies. Although this study is suggested for the Apollo 15 site, where samples and geologic setting seem ideal, a similar study could be done in the vicinity of any highlands base.

A SEARCH FOR LUNAR MANTLE XENOLITHS. David J. Lindstrom, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130

Most of our knowledge of the rocks that make up the earth's upper mantle comes from studies of mantle xenoliths--pieces of the mantle transported to Earth's surface by volcanic events. These rocks are rare on Earth and have not yet been observed on the Moon. Yet because of their scientific importance, a search for lunar mantle xenoliths should be a major goal of early lunar geologic exploration.

Terrestrial mantle xenoliths are most commonly found in kimberlite, a rock type of making up a negligibly small fraction of earth's surface. They are also found in a small proportion of alkali basalts, but even in classic xenolith localities, they comprise a small fraction of the local rocks. Thus it is not surprising that lunar xenoliths have not been observed, since the probabilitites of finding terrestrial mantle xenoliths by limited sampling in a few places would be minimal.

Very little is currently known about the mechanisms of lunar eruptions, because the detailed field geology necessary has not been done. Lunar magmas in general are much depleted, relative to terrestrial lavas, in the volatile components required for the violent eruptions needed to transport xenoliths from depth. Also, they are less viscous, but whether this leads to faster eruption or easier sinking of xenoliths is not known.

Where should a search for lunar mantle xenoliths be conducted? So called "dark halo craters" are interpreted as being volcanic craters, as opposed to the much more common impact craters. There are at least several thousand such craters, although some skepticism is in order. Shorty crater at the Apollo 17 site was long thought to be volcanic, but turned out on closer inspection to be an impact crater. Yet close to Shorty crater, the "orange soil" was discovered. This consists of glass spherules rich in volatile elements (F, Cl, Cu, Zn, Pb, etc.) and is widely interpreted as a product of volcanic fire fountaining. Deposits of orange glass may be extensive and if their interpretation as early phases of basaltic eruptions is correct, they may be well observed beneath later basalt flows. Orange glass and other volatile-rich deposits appear to be the first places to look for xenoliths.

Another possibility is that impacts, or eruptions triggered by them, can carry lunar mantle samples to the surface. Large scale mapping of impact ejecta are needed to better understand large basin-forming impacts.

Lunar mantle samples would be extremely valuable in understanding the formation of lunar basalts, which comprises a substantial part of understanding the planet's evolution. If they exist, they are most likely very rare, since not even fragments of them have yet been identified in returned lunar samples. Finding them will most likely require an intensive search of the type that could only be conducted from a permanent lunar base.

A CLOSER LOOK AT LUNAR VOLCANISM. **D. Vaniman** (J978) and **G. Heiken** (D462), Los Alamos National Laboratory, Los Alamos, NM 87545, and G. J. Taylor, Institute of Meteoritics, Univ. of New Mexico, Albuquerque, NM 87131

Although most dramatically a surface process, volcanism and volcanic rocks allow us to probe the nature of a planet's interior and to decipher its thermal history. Since volcanism has played a major role in lunar history, it is important to consider what is known about it, the questions remaining to be answered, and the means by which answers might be obtained.

Using lunar samples, remote sensing techniques, and photogeologic studies, scientists have expended considerable effort to understand volcanism on the Moon. Mare basalts can be divided on the basis of titanium content into three main types (high-Ti, low-Ti, and very low-Ti), which allows available samples to be mapped across the lunar surface by correlating their spectral reflectance properties with Earth-based spectral studies of the moon's nearside (where almost all mare basalt flows are concentrated). On the other hand, those same spectral studies suggest that the samples we have are not nearly sufficient to represent the observed spectral variability; there appear to be more than 13 types of mare volcanic rocks. Moreover, studies of complex, impact-produced breccias from the lunar highlands reveal that still other types of mare-like volcanic rocks once erupted on the Moon. In addition, there are enough data from the Apollo missions to indicate that the volcanic history at a given site was as complex as the volcanic evolution of large flood basalt provinces on Earth. Our understanding of lunar volcanism is thus incomplete.

Improving our knowledge of lunar volcanism requires answering several questions: 1) What are the basalt compositions? Answering this questions will allow more accurate interpretations of the Moon's interior and will give a better inventory of material compositions available near the surface. 2) How old, and how young, are lunar volcanic rocks. Radiometric ages range from 3.2 to 3.8 Gyr for basalts collected from maria, but photogeologic and sample studies indicate that both older and younger volcanism occurred on the Moon. 3) Do evolved lunar magmas (modified and more silicic) occur near the Moon's surface? Virtually all of the samples returned are basaltic, but a few intriguing samples of more silicic magma types are known. Magma evolution could concentrate elements and minerals that are otherwise rare on the Moon. Even among basaltic compositions, the possible gravitational accumulation of common minerals (e.g., ilmenite) in large low-viscosity flows could yield local concentrations of useful minerals. Intrusions may also occur, with possible further fractionation and chemical concentration. 4) How extensive a role have volatile elements had in lunar volcanism? Many volatile elements have been tentatively correlated with lunar pyroclastic eruptions (e.g., halogens, Pb). Closer studies of pyroclastic deposits will reveal much about processes in the lunar interior. Gas-related lava features (e.g., vesicles, pipes, pyroclastic deposits) and features that could act as cold traps (fissures, lava tubes) are targets for closer examination. 5) What are the volumes, thicknesses, and vent locations, and what kinds of intercalated pyroclastics or soils exist between mare lava flows? Soils preserved between successive lava flows may contain a record of ancient solar activity during a discrete time interval. Knowing lateral extents and thicknesses of lava flows might also be important for deciding where to build structures that require foundations in bedrock.

Answers to these questions require a closer study of the Moon. An ideal method for approaching the first question is the Lunar Geoscience Orbiter, which would provide excellent coverage of exposed lunar volcanic features. The other questions will require closer studies on the lunar surface, ranging from mapping and sampling of exposures--as within rilles, craters and fissures--to geophysical and drill-core studies.

THE GEOLOGIC STUDY OF LUNAR VOLCANIC ROCKS AS SUPPORTED BY A PERMANENT LUNAR BASE. R. L. Korotev, Dept. of Earth and Planetary Sciences and The McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130

Earth and Moon share a history of basaltic volcanism, but there are some important differences. Terrestrial volcanism is still occurring whereas lunar volcanism appears to have ceased. Terrestrial volcanics are rich in water, carbon dioxide, and many other gaseous and otherwise volatile constituents which are an important driving force in many eruptions. Volatiles, most notably water, are rare to essentially absent in all lunar rocks, including the basalts. The mineralogy and chemistry of the the basaltic rocks from the two planets are distinctly different from each other yet the diversity on either planet is great.

Because volcanic magmas derive from material which is too deep to sample in any other way, the study of volcanic rocks is an important tool used to infer the nature of the interior of both Earth and Moon. Although we have been studying samples of basalt rock returned by the Apollo missions for 10-15 years and have learned many important things about lunar volcanism, some of the most basic questions about the lunar volcanic processes have not been answered satisfactorily. Many of these are kinds of questions that can be answered easily about volcanic areas on Earth because (1) we have trained geologists who know where to go and what to look for, (2) any exposed area can be properly explored and mapped, (3) as a result of (1) and (2) we can have very strict geologic control over the samples collected for subsequent analysis, and (4) we are not usually unreasonably restricted in the amount of material we can return from the field for subsequent analysis, thus a sufficient number of samples can be selectively collected to systematically characterize a region or test a hypothesis. These were advantages not available during the Apollo missions. The Apollo astronauts had little time or experience to do geologic field work in the manner needed to answer the questions we have today, many of which, however, we would not have thought of asking prior to studying the samples they returned.

We now have many ideas for research that we, as geologists, would like to do if we had the opportunity to do field work from a lunar base. Although we can ascertain something about the structure of the lunar volcanic flows from the existing orbital photographs and the maps that have been prepared from them, we have little actual 3-dimensional information about this structure. The first-order business would be to map flows as is done on Earth. Existing data could be used to locate potential regions of study. Ideally, however, geochemical data and high-resolution images from a lunar polar orbiter would be used to locate the most interesting regions. The best areas for the next step, that of ground-based mapping, would be those in which the cross-section of the flows are already exposed. One such area is Hadley Rille at the Apollo 15 site where layers of basalt flows were clearly visible on the far wall of the rille. Other possible study sites would be areas where craters have exposed the stratigraphy. This would be the lunar equivalent of using road cuts and quarries to aid in mapping. Drilling cores into the lava flows and selectively excavating down from the surface could provide much additional valuable information.

Most lunar volcanic rocks are lavas that flowed into the large crater basins left by impacts of giant meteorites into the early lunar surface. These are the lunar "seas" (maria). The orbital photographs and Apollo sample data suggest that these were not filled all at once, but by a sequence of flows. Although we have dates of formation of many of the individual basalt samples, we don't know their relationship to the flow sequence. Mapping combined with geochronological studies of the samples would allow us to learn whether successive flows are all about the same age or whether a significant time period separated the eruptions. Samples for dating studies could be obtained through a vertical cross-section or by a traverse from the center of a mare basin to the rim.

We know from our study of Apollo mare basalts that several different kinds of basalt occur at each of the landing sites. Even in different samples believed to be of the same general type there are compositional and mineralogical differences. On Earth it is common to see a regular variation in chemical and mineralogical composition with successive lava flows from a single volcano. These occur for a variety of reasons. The composition of the magma changes as it cools and mineral crystals settle out of it. Source chambers can be replenished with magmas of different composition. Magmas can interact with the cold rock through which they pass to reach the surface. Magmas from two different sources can mix before reaching the surface. All of these can cause successive lavas to differ in composition. This variation with time provides some of the most important information about the genesis of the lavas. It has been a problem in the interpretation of the Apollo mare basalts whether differences in composition between samples is significant. On Earth, samples collected from a single flow can differ as greatly as samples from different flows, depending on the conditions of crystallization. Hence, it is necessary to evaluate the intraflow variation before trying to interpret the interflow variation. Detailed vertical and horizontal sampling would make this comparison possible. This type of systematic field study could only be done with the support a lunar base.

A lunar base would also provide us with the opportunity to explore for volcanic features we would expect to find, based on our terrestrial experience, but that were not observed on any of the Apollo missions. We suspect from the orbiting geochemical and geophysical experiments carried by the Apollo command modules that areas of intrusive volcanics, those magmas that did not reach the surface but have crystallized some distance below the surface, occur on the lunar farside. Because these bodies have cooled more slowly the processes of crystal fractionation will have proceeded more efficiently and layered concentrations of minerals may occur. Magnetic techniques could be used to locate such areas, as oxides of iron and titanium are thought to be likely products of such differentiation processes and these would be useful as resources. Similarly, lavas may have filled small local craters and formed pools or lakes. The chemical and mineral stratigraphy of such "lava lakes" on Earth have been useful for understanding the detailed processes of magma crystallization.

Many of the analyses and experiments associated with sample collection could be done at a moderately sophisticated lunar base. For example, thin sections could be prepared for microscopic examination and some kinds of chemical analysis such as X-ray fluorescence spectrometry could be done. These techniques would identify samples that were important enough to return to Earth for age dating, trace element analysis, and other experiments which may be too complicated to do at a lunar base. Many of the aspects of field geologic study would be natural extensions of activities such as excavation, general reconnaissance, and mapping which are necessary to the construction and maintenance of a lunar base.

In summary, the study of lunar volcanic rocks would be immensely aided by the support of a lunar base because maps of their structure in 3-dimensions could be prepared, samples with known relationships to this structure could be collected, and samples large enough to be representative of the structural units could be studied. Although these advantages have been argued specifically in terms of volcanic rocks, they apply to the geologic study of the lunar regolith, cumulate rocks, and mineral resources as well.

LAYERED INTRUSIVES ON THE MOON: A SOURCE OF CHROMITE DEPOSITS?

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The lack of water on the Moon is of great significance, for many of the processes which form ores on Earth have not been operative on the Moon, i.e., hydrothermal ore formation. However, some ores on Earth are the result of metallogenesis in dry magmatic systems -- results of mineral fractionation and crystal settling independent of the presence of water. The mineral chromite, $FeCr_2O_4$, of mafic-ultramafic intrusions constitutes the world's major source of the strategic metal, chrome. This chromite occurs in mafic "strata" of large layered igneous complexes, often associated with platinoid metals. However, only 3 layered intrusives -- the Bushveld of Transvaal; the Great Dyke of So. Rhodesia; and the Stillwater complex of Montana -- are known to contain substantial amounts of chromite. Layered complexes originate as large igneous intrusions where the mechanism is one of fractional crystallization leading to the settling of successive crops of crystals on the progressively rising floor of the intrusive sheet concerned. Related silicate assemblages embrace almost the complete range of mafic and ultramafic rocks -- peridotite, dunite, pyroxenite, norite, and to a lesser extent, gabbroic and anorthositic types. In fact, the presence of these rock types is evidence that fractional crystallization and gravity-controlled, crystal settling have been effective.

The non-mare portions of the Moon, the Highlands, consist of just these rock types, and various theories of lunar crustal formation always consider layered intrusions as an essential component. The very existence of KREEP indicates that processes which can fractionate elements to extremes do occur on the Moon. Likewise, mineralogic and chemical variations in lunar basalts due to crystal settling have been observed. In summary, **the same processes occurred in the mafic plutons on the Moon as on Earth.** In addition, chromites and Ti-chromites are abundant in mafic rocks, as well as in mare basalts, on the Moon. In fact, our studies have shown that almost all lunar rocks contain some chromite.

Do chromite deposits exist on the Moon? The Moon remains largely unexplored. Only a few of the 9 sitesvisited have been sampled to any geographic extent. Such a sampling of igneous rocks on Earth would be unlikely to reveal the presence of ore bodies. Therefore, it is not surprizing that ores have not been sampled on the Moon. However, all the requisite conditions mentioned above are present such that accumulations of chromite are to be expected.

As an sidelight to this discussion, Dietz (1964, J. Geol. 72) has shown that on Earth, large meteorite impacts may either produce or trigger igneous processes involving large volumes of magma at depth with subsequent ore deposits. In fact, the largest Ni deposit in the world at Sudbury, Ontario, is thought to involve such an origin. It is interesting to speculate on the possibility of such ore deposits on the Moon, caused by large meteorite impacts such as formed the mare basins or Copernicus, for example. There is considerable evidence from research on highland rocks that such impacts undoubtedly triggered various igneous activity at depth, possibly leading to many of the vast variety of lunar plutonic rocks, which we have reported on in the Prodeedings of the Lunar & Planetary Science Conferences.

How do we explore for such deposits? The exploration would involve a considerable amount of fieldwork, the old, yet proven prospecting technique. It would probably be advisable to search the areas in and around certain large crater excavations, such as Copernicus, for evidence of such ore-bearing rocks. Once a likely area is outlined, deep trenching, stripping, core drilling, etc. could be initiated to further evaluate the prospect. This type of prospecting can be supplemented with detailed ground magnetic and gravity surveys. It is probable that large, economically-feasible concentrations of ore minerals occur on the Moon. It but remains for their discovery!!

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MASS EXTINCTIONS AND IMPACT CRATERING

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There remains little doubt that one of the most severe mass extinctions is temporally related to a large impact event. Approximately 85% of all biomass vanished at the Cretaceous/Tertiary boundary some 65 million years (m.y.) ago. Platinum group elements (e.g., Iridium) are unusually enriched at this boundary, and their relative abundances are unlike those of terrestrial rocks, but identical to some meteorites (1). This geochemically unique layer is of global nature (2). In addition, it contains mineral fragments which display deformation features only produced by transient shock waves and their attendant, very high pressures (3). The Eocene/Oligocene extinction (34 m.y. ago) might also have been caused by meteorite impact (4).

The temporal distribution of all mass extinctions during the past 250 m.y. reveals striking periodicity with an average cycle of some 26 to 28 m.y. (5). In addition, the terrestrial cratering record may also have periodicity of some 30 to 33 m.y. per cycle (6). Importantly, both cycles seem to be in phase (6). The solar system passes through the plane of the galaxy once every 33 m.y. It has been estimated that $>10^{12}$ comets populate the outer fringes of the solar system. Massive interstellar clouds and changing proximity to other solar systems will induce gravitational perturbations of this comet reservoir and will inject some of its members into trajectories that cross the inner solar system (6).

The statistical data base to infer periodicity in the terrestrial cratering record is poor, however, and will probably remain so (6, 7). Erosion of and -- more commonly -- burial by sedimentation causes only a select set of craters to be recognized. By contrast, the lunar cratering record is extremely well preserved. It is suggested to date the formation times of a statistically significant number of lunar craters (e.g., 500-1000). This enlarged data base will allow more vigorous tests to accept or reject a causal link between impact cratering and mass extinctions.

These investigations mandate long range mobility (approx. 1000 km) for sample aquisition. The analytical aspects of isotope geochronology are well in hand and could be performed either on the Moon or in the terrestrial laboratory.

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CAN A RECORD OF THE 65 MILLION YEAR TERRESTRIAL MASS EXTINCTION EVENT EVER BE FOUND ON THE MOON?

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ND 185020

A lunar base would provide an excellent opportunity to investigate detailed regolith stratigraphy. Use of a trench or strip mine cut would be analogous to the use of road cuts or mining cuts on earth as locations for detailed stratigraphic studies. Such cuts are far superior to cores of similar depth because the strata can be examined in detail in two dimensions in a single cut or in three dimensions in two or more cuts. A trench or mine cut at a lunar base would provide new information on such problems as the distribution of ejecta around craters, the continuity of ejecta layers and the rate of thickness decrease away from the crater, the disruptive effects of secondary projectiles and of material in rays, and the possibility of lunar-wide marker beds from major lunar impacts.

An interesting type of lunar-wide marker bed may be present on the moon which is related to major impacts on the <u>earth</u>. We know that material can be ejected from the moon by impacts and can make its way to the earth. The evidence are the meteorites (ALHA81005 and YAMOTO 791197) recently found in Antarctica which are both generally accepted to be from the moon. Positive confirmation of this material as lunar ejecta has been made by careful chemical and isotopic analysis including oxygen isotopic differences and manganese/iron ratios. The converse situation may also exist. Large impacts on the earth may splash enough ejecta at sufficient velocity so that some of it leaves the earth's gravitational field and may find its way to the moon. This ejecta may include fine material similar to microtektites which are found in ocean sediments and are clearly ejecta from large impacts. If sufficient material of this sort reached the moon it might form a thin marker bed which would be identifiable in a lunar trench or mining cut. While such material would be mixed with soil when it impacted the moon, it might still be abundant enough to form a distinguishable marker bed which could be identified stratigraphically.

A likely place to look for such material is at the 65 million year zone in the regolith. This time corresponds to the Cretaceous-Tertiary boundary on earth and is the time of an apparently world-wide zone marked by a high iridium anomaly. The iridium anomaly and other types of evidence suggest that this time-stratigraphic marker on earth represents ejecta from a very large impact of an asteroid or comet on the earth. As the ejecta layer is world-wide and contains both projectile material and terrestrial material, it seems possible that some of this ejecta escaped the earth's gravitational field and made its way to the moon. A search for this material could be concentrated in the part of the regolith likely to represent an exposure time of 65 million years ago. The advantage of a trench or mining cut over a core arises from the probability that the marker bed is likely to be preserved only at some places in the regolith but will have been destroyed at other places by subsequent impact and gardening. While the impact of material coming from the earth at high velocities would surely cause considerable disturbance to regolith stratigraphy, the disturbed zone itself might be identifiable. If the earth-derived material contained appreciable Fe^{+3}, it might even form a colored zone. Individual fragments of earth-derived material might be identified by the isotopic and chemical criteria used to confirmed the origin of the lunar meteorites but applied in reverse.

EXPLORATION SELENOPHYSICS

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Although our understanding of gross lunar structure has been greatly increased by data from a very few collection sites, much more information on local structure, stratigraphy, and mineral assemblages must be acquired before our comprehension of lunar geology is sufficient to target economically viable areas. Numerous geophysical techniques developed for studying various aspects of the Earth's geology can be useful for enhancing our knowledge of the Moon in terms of economic mineral deposits as well as local, regional, and deep structure. However, the basic assumptions implicit in application of these techniques are not always valid in light of the radical differences in the nature and occurrence of lunar materials and natural potential fields. Some methods may be applied in essentially the same manner on the Moon as on the Earth; others require substantial modification in instumentation and methodology. In all cases, absence of water and continuous strata as well as differences in rock histories preclude straightforward models based on previous terrestrial experience.

In general, nearly all passive exploration techniques can be applied on the Moon without major equipment modifications, for example, gravity, magnetics, passive electrical, passive electromagnetic, passive seismic, heat flow, and radiometry. On the other hand, most active techniques such as active electrical and active electromagnetics will require major equipment modification. Many of these techniques will require major development of substantially more complex theoretical models in order to interpret the acquired data, for instance, all electrical, electromagnetic, and seismic techniques. The vastly different physical properties of the Moon may affect the order of importance of the techniques as they are traditionally applied on the Earth. Gravity and magnetics would logically be the first techniques applied because they are relatively inexpensive and large quantities of data can be collected rapidly. Unfortunately, they do not have the subsurface resolution that many of the active techniques possess. Active seismic techniques will probably not have the prominence that they have been assigned on the Earth because of the extreme signal attenuation in volcanic terranes as well as statigraphic complexity introduced by meteor impacts. Conversely, DC resistivity may become a very important technique (after substantial modification) because of its sensitivity to highly resistive terrane typical of the lunar surface. Some techniques such as induced polarization and self potential may be of little use on the Moon because of the lack of water.

SEARCH FOR VOLATILES AND GEOLOGIC ACTIVITY FROM A LUNAR BASE,
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A lunar base can be used as a central point from which to monitor lunar geologic activity and to search for lunar volatile emissions. Evidence for the occurrence of lunar volatile emissions has three primary forms: reports from Earth-based astronomers of lunar transient events (1), observations of gases made by detectors placed on the Moon during the Apollo program (2,3), and localized out-of-equilibrium decay rates of radon and radon daughter isotopes observed by alpha spectrometers on board the Apollo 15 and 16 command modules as they orbited the Moon (4). We know of lunar seismic activity, both externally generated by impact and of internal origin, from seismometers placed on the Moon during Apollo (5). The search and monitoring project proposed here would be done in a twofold effort: with a grid of instruments placed over the lunar surface, and with a polar orbiting lunar satellite monitored by base personnel.

Manned roving vehicles would be used to place a grid network of instrument packages out to as great a distance from the lunar base as the vehicles' range will allow. Each package would include seismometers to monitor moonquakes, plus mass spectrometers to detect and characterize any gas molecules or ions that may be present. The packages would also observe the solar wind and include instruments to detect cosmic rays. The trips used to emplace the instruments would also be used to gather geologic samples.

The polar orbiting satellite would look for obscurations or anomalous brightenings, and would carry instruments capable of taking spectra at ultraviolet, visible, and infrared wavelengths. It would also carry a mass spectrometer to look for lunar gases and an alpha spectrometer to look for radon and radon daughter isotopes on the lunar surface. Because the satellite will have the task of surveying the Moon in general, as well as searching for volatiles in particular, it ought also to carry gamma-ray and X-ray spectrometers, plus a radar sounder.

This project has three primary purposes. First, to use the seismic network to characterize the sources of moonquakes, and to define the internal structure of the Moon, more closely than was possible during Apollo. Second, to determine the extent to which the Moon is outgasing at the present day (and possibly to determine whether or not lunar transient events actually occur). Third, to locate the sources of any volatiles found. In addition, the secondary purposes of surveying the Moon, monitoring the solar wind and cosmic rays, and collecting lunar samples are also of significant scientific importance.

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A PARAMETRIC COST MODEL FOR EVALUATION OF SPACE RESOURCE UTILIZATION TECHNOLOGIES, by Michael C. Simon, General Dynamics Convair Division, San Diego, California; Contributing analysts: James Carter, University of Texas, San Antonio; Andrew Cutler, University of California, San Diego; Rocco Fazzolare, University of Arizona; Joel Greenberg, Princeton Synergistics, Inc.; and Robert Salkeld.

This paper presents the preliminary results of a parametric systems and cost analysis which has been developed as a tool for evaluating alternative approaches to utilization of space resources. The specific application discussed in this paper is a parametric analysis of liquid oxygen (LO_2) production on the Moon. A baseline scenario for production of LO_2 from lunar ore and delivery of this LO_2 to low Earth-orbit (LEO) is defined, and the major systems required to support such an enterprise are identified. Fifteen principal variables influencing the capital emplacement and operations costs of this baseline scenario are defined and organized into a parametric cost model. A sensitivity analysis is performed to identify the impact of each of these variables on the costs of lunar LO_2 production. The cost model and sensitivity analysis are structured with emphasis on permitting evaluation of alternatives to the baseline scenario, rather than for developing conclusive cost estimates for the baseline scenario. After ranking the cost variables according to their impact on the cost of lunar LO_2 production, a number of key technologies are evaluated with regard to their potential effects on the cost factors. For each technology issue an economic weighting factor is derived, which provides a quantitative measure of the impact of each technology on the economics of the baseline LO_2 production scenario. On the basis of these economic weighting factors, recommendations are offered regarding which types of near-term technology development activities should be initiated to maximize opportunities for cost-effective utilization of space resources.

AN ALKALI HYDROXIDE BASED SCHEME FOR LUNAR OXYGEN PRODUCTION

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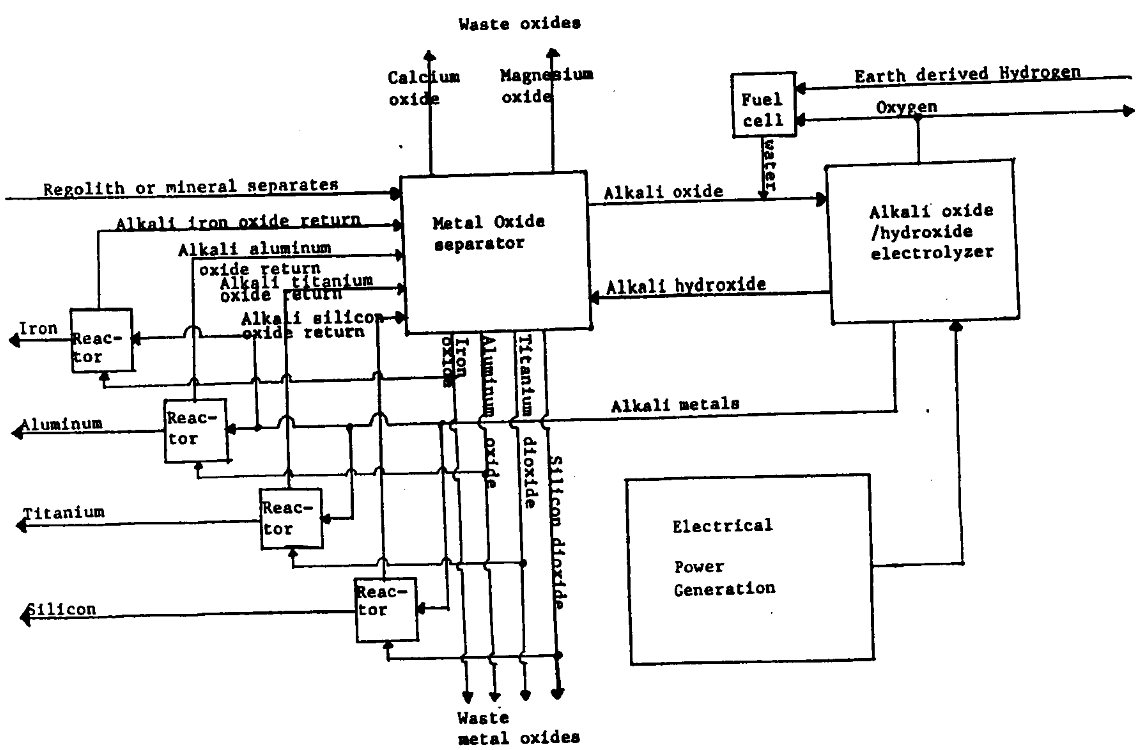
Production of oxygen and metals from lunar materials may be one of the first steps in creating a space based economy. There have been many studies which considered the moon as a source of oxygen, metals or other materials for use in space manufacturing. The actual chemical processes which would be used to win oxygen and metals are usually poorly defined, and certainly represent a part of the engineering which will prove somewhat challenging.

Literature data indicate that molten (Na,K) OH will dissolve bulk lunar soil or mineral separates, and that adjusting the water content of the melt will cause pure metal oxides to precipitate. Electrolysis of molten (Na,K) OH produces alkali metals and oxygen. The alkali metals can be used to win iron, silicon, aluminum and titanium from their oxides. Due to the nature of the process, only the desired metal need be won, unlike many proposed processes which require that all input material be separated into its component elements to recover the reageant.

This process uses (Na,K) OH as a reageant. $(Na,K)_2O$ is reasonably lunar abundant (.5-1% of bulk soil). Only the 2.2% of the reageant which is hydrogen need be imported from earth. Adequate economy can be acheived with far worse reageant recovery than in processes using entirely terrestrial derived reageants. Water loss from molten (Na,K) OH under hard vacuum is small, so plant failure will not usually result in loss of the reageant inventory as with certain other processes.

A flow diagram of the process is shown below.



A CARBOTHERMAL SCHEME FOR LUNAR OXYGEN PRODUCTION

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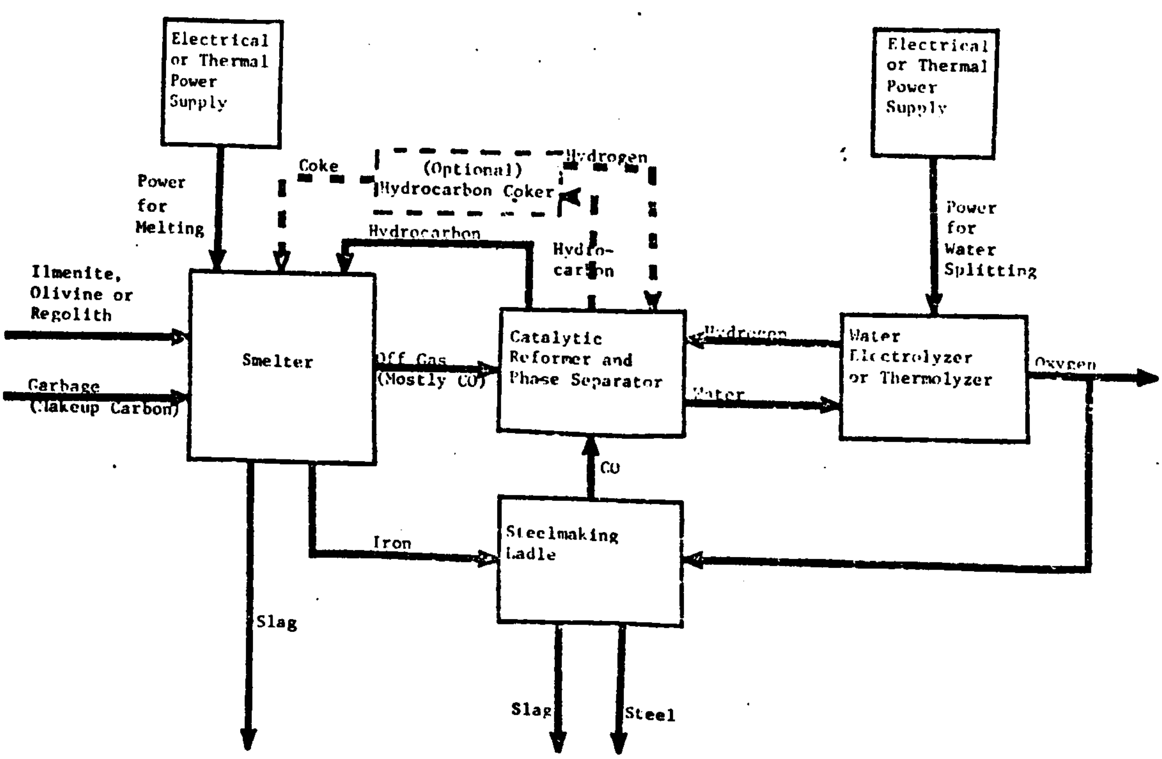
Production of oxygen and metals from lunar materilas may be one of the first steps in creating a space based economy. There have been many studies which considered the moon as a source of oxygen, metals or other materials for use in space manufacturing. The actual chemical processes which would be used to win oxygen and metals are usually poorly defined, and certainly represent a part of the engineering which will prove somewhat challenging.

It is possible to construct a process based on carbon reduction of molten lunar minerals in which every step is based on processes which have been extensively studied and utilized in terrestrial engineering practice. This process may draw on a literature and art so extensive that NASA simply cannot duplicate it for any process intended for space use only. Preliminary work on this process by Rosenberg et al. in the '60's proved it's basic feasibility, and current work shows it to be economical and reliable.

The basis of the process is reduction of iron containing minerals with carbon or hydrocarbon, oxygen steelmaking for carbon recovery, reforming the carbon monoxide from the reduction and steelmaking steps with hydrogen to form hydrocarbon, optional coking of the hydrocarbon and electrolysis or thermolysis of the water produced. This process is shown in the flow diagram below. Note that reageant (carbon) makeup comes from lunar base garbage, not from material specifically imprted as a reageant.



PLASMA ANODE ELCTROLYSIS OF MOLTEN LUNAR MINERALS

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Oxygen for propellant use may be the single largest commodity used at a lunar base. If it can be economically manufactured at a lunar base, delivery of liquid oxygen to low earth orbit (or other useful orbits) may greatly enhance the economy of the space transportation system. It is thus desirable to have a simple method of oxygen production from lunar available materials. Plasma anode electrolysis of molten lunar minerals is such a method.

There are no conveniently available fluxes, solvents or reducing agents available on the moon. The necessary redox chemistry to win oxygen from lunar minerals must be conducted thermally or electrically. The electrical route is simpler, operates under less severe conditions, and does not have the rather severe engineering constraints impsed by heat transfer in a thermal system. Electrolysis also draws on the knowledge acquired about electrochemistry in molten slag (similar in composition to lunar minerals) which has been acquired during the last 50 years of metallurgical research. Arc electrolysis provides a solution to the problem of how to prevent consumption of the anode in mineral electrolysis - the electrode is removed from the melt, and is cooled to a low enough temperature that it is not consumed by the hot oxygen generated in the process.

This process is extremely simple, and has only one drawback - power efficiency. Only a small portion of the electrical energy put into the system goes into winning oxygen from the mineral feedstock. The rest is rejected as waste heat. The plant mass is thus dominated by electrical power generation equipment. The exact electrical efficiency and the exact achievable specific power of the power system are the major determiners of plant economy. Power efficiencies of 7 to 20% can be reasonably expected. With current solar cell systems or the projected 100 KW_e SP-100 reactor this gives payback times on the lunar surface of several months.

Experimental research has shown that (simulated) molten lunar minerals are quite electrically conductive, and are able to support an arc under conditions reasonably close to those which would obtain in startup and operation of an oxygen producing plant. Electrolysis does occur with high electrical efficiency, except in melts rich in titania. In general, all of the iron is removed from a melt before any of the other elements are. The increase in silica content on continued electrolysis reduces the fluidity and conductivity of the melts which lowers the power efficiency and eventually extinguishes the arc. An arc electrolysis plant would probably operate best if only a small portion of the oxygen in the feedstock were won. Since there is excess waste heat in the arc electrolysis step, this has little effect on plant efficiency.

ELECTROSTATIC CONCENTRATION OF LUNAR SOIL ILMENITE IN VACUUM AMBIENT. William N. Agosto, Lockheed Engineering and Management Services Company, Inc., Houston, TX, 77258.

Hydrogen reduction of ilmenite appears to be one of the more practical schemes for the production of lunar oxygen and iron for space utilization (Williams & Mullins, 1983). Ilmenite is abundant in many lunar mare basalt and soil samples (McKay & Williams, 1977). Lunar soil ilmenite is also accessible. Agosto (1984) reported successful electrostatic concentration of lunar ilmenite in the 90-150 micrometer fraction of Apollo 11 soil 10084,853 from 10 to approximately 50 volume % in nitrogen ambient after the bulk of the soil agglutinate fraction had been removed with a hand magnet. More recently ilmenite in the 90-150 micrometer fraction of 10084,853 has been successfully concentrated by electrostatic means from approximately 3 to 20 volume % in vacuum at 10^{-5} torr with the agglutinates present (Fig. 1). Vacuum ambient was used to partially simulate lunar conditions and because attempts at electrostatic separation of 10084,853 in nitrogen with the agglutinates present caused agglutinate coating of the high voltage electrode probably due to nitrogen ion charging of the soil feed.

Both vacuum and nitrogen ambient ilmenite concentrates of 10084,853 were obtained in one pass through a slide type electrostatic separator based on industrial designs and fabricated by Lockheed Engineering and Mgt. Services Co. at the Johnson Space Center in Houston, TX. Soil feed temperature was approximately 150°C in both cases.

The results of the vacuum run in Fig. 1 show that lunar soil ilmenite behaves like a semiconductor with concentration increasing in the direction of the high voltage electrode from 3 volume % in the low numbered bins to 20 volume % in the two final bins #6 & 7. The agglutinates behave like nonconductors and decrease from 75% in the first bin to 35% in the 7th and last bin. The polyphase component plotted in Fig. 1 refers to soil particles that are about half ilmenite. That fraction increases from 1% in the first bin to 12% in the 7th and last bin. If added to the ilmenite, the polyphase fraction would increase the ilmenite bearing concentration to approximately 30 volume % in the last two bins. Ilmenite bearing phases in the concentrate were confirmed by SEM/EDS analysis.

The most promising aspect of the vacuum electrostatic run is the consistent behavior of the heterogeneous agglutinate fraction. It is expected that optimization of the apparatus design and run conditions can capitalize on that advantage, but more work needs to be done.

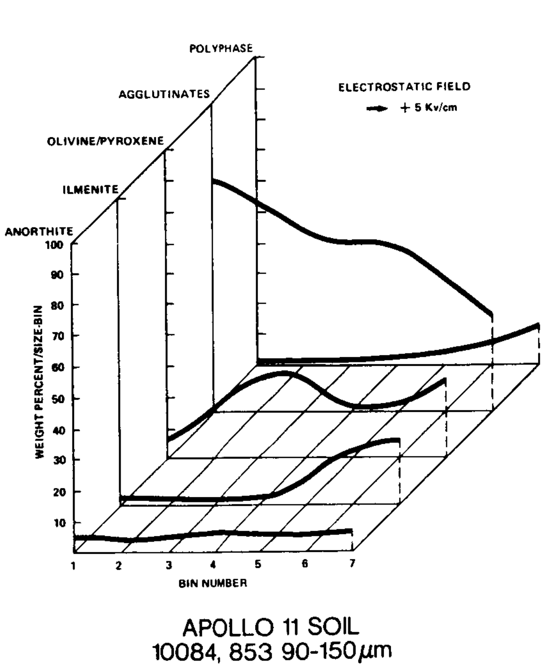

Fig. 1. Vacuum electrostatic separation, one pass.

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THE KINETICS OF ILMENITE REDUCTION: A SOURCE OF LUNAR OXYGEN.

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A ready source of oxygen on the Moon is requisite to a lunar base mission. A likely source for this oxygen is the mineral ilmenite ($FeTiO_3$), an abundant constituent of the lunar rocks and soil. The reduction reaction for ilmenite can be written:

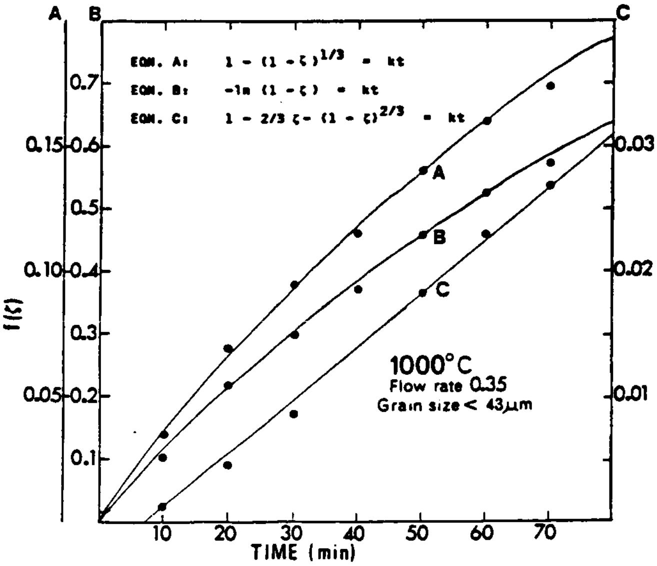
$$\underset{151.8}{FeTiO_3} = \underset{79.9}{TiO_2} + \underset{55.9}{Fe} + \underset{16}{1/2\ O_2}$$

It is apparent that such a reduction produces ≅**10.5 wt.%** oxygen. Also note the native iron as a by-product. The source of the reducing agent could be solar-wind implanted protons, i.e., hydrogen, an abundant constituent of lunar soil. In addition, the source of much of the high titanium content of lunar rocks and soil is this mineral ilmenite.

The stability relations of ilmenite in oxygen fugacity and temperature space have been established by Taylor et al. (1), and the feasibility of this reaction has already been demonstrated in the laboratory (2). However, the several factors affecting the kinetics of this reaction are largely unknown. These include: a) temperature, b) oxygen fugacity (fO_2), c) grain size, and d) ilmenite composition. The first three of these parameters was studied using pure $FeTiO_3$ as a starting material.

Ilmenite was synthesized from 99.99%$^+$ purity Fe, Fe_2O_3, and TiO_2 and equilibrated at controlled fO_2. A thermogravimetric gas-mixing (CO/CO_2) furnace, with an electrolytic cell (Y_2O_3/ZrO_2) fO_2 monitor, was used for the experiments. Various grain-size fractions of ilmenite were suspended in a Pt-wire, open basket and monitored for wt. loss due to reduction _versus_ time. An fO_2 of 1 log unit below the ilm/TiO_2+Fe stability curve was used. Experiments at different T's and at different gas-flow rates formed the data base for the kinetic considerations. The progress of reaction, zeta ( ), was calculated by the ratio of the wt. loss/total wt. loss for complete reaction; three reaction mechanisms were tested, according to Hammond & Taylor (3): growth controlled by a) activation of nuclei, b) mass transport of reacting gas, and c) solid-state diffusion thru a product layer.

An example of some of the results is shown in Fig. 1, where it is evident that the rate-controlling reaction mechanism is diffusion thru a product layer (c above). As to be expected, fine grain sizes proceed faster to completion because of increased reaction surfaces. In addition, the kinetics run with pure H_2 will have rates that predictably are orders of magnitude faster than the ones described here. However, the present runs form the basis for the complete kinetic study.



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LUNAR OXYGEN PRODUCTION FROM ILMENITE

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In any future human colonization of the moon, oxygen is clearly one of the most important materials to be supplied. It is required for both life support and propulsion. Incentives for lunar oxygen production from lunar raw materials as opposed to supplying it solely from Earth have been discussed by Criswell [1] and Davis [2]. Both conclude that more efficient use of Earth-supplied hydrogen, total propellants and available payload weights and volumes all result from lunar oxygen production.

Two types of lunar materials have been proposed as raw materials for oxygen production: ilmenite, $FeTiO_3$, and silicates such as anorthite, $CaAl_2Si_2O_8$. Both are lunar-surface-minable, occurring in soils, breccias, rocks and basalts. The silicates are considerably more abundant than ilmenite, and this would suggest a preference for them as source materials. However, the silicates present more difficult process engineering problems, and ilmenite, being magnetic, offers interesting possibilities for beneficiation. These facts, in our judgment, make ilmenite the preferable raw material.

The available processing techniques include H_2-reduction, chemical reductions with other reagents and electrochemical reduction. We have concluded that the probable best route to lunar oxygen is via H_2-reduction of ilmenite. This is best done with some kind of continuous or semi-continuous process cycle using pressurized H_2 as the working fluid. This paper discusses the various reduction options along with the reasons for our design choices.

Two potential H_2-reduction schemes are discussed and compared. The first is a continuous, fluidized-bed process with two novel heat-integration features to reduce energy demand and flowsheet complexity. The second is a semi-continuous fixed-bed process based on using Williams' heat-removal concept to overcome equilibrium H_2-conversion limitations [3]. For both schemes, the lunar environment presents some unusual and challenging design problems, but prototypes or commercial-size versions of all the required processing equipment have been built for terrestrial use. The mining and beneficiation steps are likely to require equipment with no close terrestrial analogs.

1. Criswell, D. R., Fourteenth Lunar and Planetary Science Conference, p. 10, March 16-17, 1983, Lyndon B. Johnson Space Center, Houston, Texas.
2. Davis, H. R., ibid, p. 13.
3. Williams, R. J., Personal Communication, May 1983.

LUNAR REGOLITH FINES: A SOURCE OF HYDROGEN (WATER)

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The lunar regolith fines contain an average of approximately 50-200 ppm hydrogen, as solar wind implantations. This is the equivalent of 0.04 wt. % to 0.18 wt. % water. For this material to be an exploitable source of water, it must be up-gradeable in hydrogen content by at least a factor of 10. This is mechanically possible only if a significant portion of the hydrogen occurs in a small but separable fraction of the lunar regolith fines.

This requirement was assessed theoretically. The theoretical results show that a minium 10-fold increase in volatile content is possible because both particle size and particle shape play a significant role in the relationship of volume of surface coating to grain size. For example, for a 200 Angstrom thickness coating, two-thirds of the total surface coating is found in the 5 micron and less size fraction; and a 2.5 micron size prismatic shape grain has approximately three times more surface volume of material than a 2.5 micron in diameter spherical shape grain. Non-spherical shaped grains including convoluted ones are common in the lunar regolith fines.

AN ANALYSIS OF ALTERNATE HYDROGEN SOURCES FOR LUNAR MANUFACTURE

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Earth's relatively large mass places a high energy cost on the use of terrestrial materials in space. Availability of minerals on the moon at one-sixth lower gravity coupled with ample solar energy assures that some materials required for permanent lunar bases and space exploration will be manufactured there.

Water is needed to support life. There is no known water on the moon. Confirmation of speculation on trapped ice awaits exploration of the lunar poles. Vacuum pyrolysis of lunar surface soil yields between 50 and 100 parts per million of hydrogen, originating from the solar wind. Hydrogen can be oxidized to water by suitable lunar mineral oxides.

Oxygen is also critical for life support and rocket propulsion as well. The moon contains ample oxygen in the form of rocky minerals from which it can be isolated by direct electrochemical treatment or by hydrogen reduction of lunar minerals such as ilmenite followed by electrolytic decomposition of the water produced.

Because both carbon and nitrogen are critical to sustained animal and plant life, adequate supplies must be available to maintain permanent lunar colonies. The solar wind deposits both in lunar surface soil. Carbon at 20 to 220 ppm and nitrogen at 50 to 150 ppm have been isolated from moon rocks by vacuum pyrolysis. If this source is inadequate, terrestrial C and N will have to be imported. The simplest form for their import is combined with hydrogen as methane and ammonia.

Terrestrial hydrogen must be imported in some form to supply the critical need of water and oxygen for life support until lunar vacuum pyrolysis is established and thereafter as well if the supply of lunar hydrogen is inadequate. The importation of liquid hydrogen is generally considered but liquid methane and liquid ammonia should also be evaluated.

A weight penalty is associated with importing hydrogen as methane or ammonia (see Table I). However, higher boiling points reduce boiloff during transport and storage offsetting the penalty. In addition, methane and ammonia can be chemically converted into other compounds by industrial processes for which effective catalysts have been developed and they can be used directly for reduction of ilmenite.

TABLE I

GASEOUS HYDROGEN SOURCES

	Hydrogen	Methane	Ammonia
Molecular Weight	2	16	17
Hydrogen % by Wt	100	25	17.6
Boiling Pt, C	-252.8	-161.5	-33.35
Liquid density at bp, g/cc	0.070	0.424	0.68

*Mound, Miamisburg, Ohio 45342, is operated by Monsanto Research Corporation for the U.S. Department of Energy under Contract No. DE-AC04-76-DP00053.

A LUNAR-BASED PROPULSION SYSTEM

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ABSTRACT

As activities in cis- and trans-lunar space and on the moon increase during the 21st century, the use of a lunar-based propulsion system, refueled by propellants manufactured from lunar resources, may offer large cost savings when compared with a space-based propulsion system refueled from the earth. Oxygen/hydrogen, LO_2/LH_2, bipropellant propulsion appears to be attractive because of its estimated high delivered specific impulse, i.e., 485 sec. However, difficulties associated with the long-term storability and low density of LH_2 detract from this performance. Other bipropellant combinations may have advantages in this context.

The potential utility of the oxygen/silane, $LO_2/LSiH_4$, bipropellant combination for use in a lunar-based propulsion system and the potential for the on-site manufacture of lunar oxygen and silane are considered in this paper.

It appears that oxygen and silane can be produced from common lunar mare basalt in an integrated facility. The carbothermal process uses lunar materials efficiently to produce oxygen and silane-precursors with minimum terrestrial resupply. The production of silane from lunar materials may require a key lunar-produced intermediate, magnesium silicide, Mg_2Si. Mineral acid terrestrial resupply will be required to produce silane by this synthesis.

It appears that the propellant properties of oxygen and silane are more than adequate to support the development of a lunar-based propulsion system. Silane is stable and storable in space and lunar environments and has properties which are compatible with those of oxygen. The estimated delivered performance of the propulsion system is 340 to 350 sec at a mixture ratio of 1.50 to 1.80. Penalties normally associated with pressure-fed propulsion systems may be minimized in the lunar environment, i.e., 1/6 g. A pressure-fed propulsion system may prove to be quite competitive with a pump-fed system.

INTEGRATED ECOLOGICAL/BIOLOGICAL AND ENGINEERING PRINCIPLES APPLIED TO AN ECOLOGICAL LIFE SUPPORT SYSTEMS (CELSS) ON THE MOON

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Development and maintenance of self-sustaining Closed Ecological Life Support Systems (CELSS) must be based on fundamental ecological/biological principles and innovative engineering techniques. Whether they support life on a space station, the lunar surface, or elsewhere, CELSS could be designed conceptually to simulate the closed system of the Earth, in which the only input is solar energy for primary productivity. All other materials are recycled in an interconnected system. The critical connecting parts of the cycle are often biological activities of innumerable plant, animal, and microbial species. Our understanding of these relationships is often limited. Currently, research is being performed into various biological issues, and small Earth-bound CELSS prototypes are being planned. However, application of this research to specific large-scale lunar applications will require an extensive integration of biological and engineering research and development.

CELSS will be addressed from an ecological perspective of potential system components and flows on the moon, emphasizing relationships associated with primary productivity, assimilation capacity, and species and genetic diversity. Biological constraints due to extending Earth principles to lunar application will be shown. On the moon, the space, time, matter, and energy required for food production must be reduced as much as possible and will demand the highest efficiency from a CELSS. Minimum requirements for closed cycle food production will be discussed, and several systems will be proposed and discussed.

CELSS also will be addressed from an engineering and systems viewpoint to identify constraints and possible solutions to biological requirements. Two major types of engineering constraints exist, including those that pertain to: (1) the development and operation of the CELSS, and (2) the interaction of CELSS with other lunar and transportation systems and operations. An example of the first type is protection of plants from ultraviolet radiation while maximizing exposure to photosynthetically useful wavelengths. An example of the second type is the effects of a CELSS on the transportation system required from Earth and the interaction of a CELSS and power/thermal, data/computer, and other lunar facilities.

A systematic matching of biological and engineering constraints will be presented in a matrix format, with various classes of problems highlighted. Difficult to solve biological/engineering problems will be contrasted with relatively easily solved problems. Thus, the research, development, and demonstration work with CELSS will be prioritized from a biological/engineering viewpoint.

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SYSTEMS ENGINEERING ASPECTS OF IMPLEMENTING SUPERCRITICAL WATER OXIDATION TECHNOLOGY IN A LUNAR BASE ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEM; Melaine S. Meyer, NASA, Johnson Space Center, Houston, Texas 77058.

The NASA is studying the feasibility of establishing a lunar base as a followup or parallel venture to the Space Station. For these studies, planning commonality of lunar base systems with their counterparts on the Space Station is generally a good policy for saving development cost. However, this policy should not exclude the consideration of different systems which may offer substantial advantages in lunar base application, such as the proposed Environmental Control/Life Support System (ECLSS) introduced in this report.

The distinguishing technology in the new concept is supercritical water oxidation (SCWO). The properties of supercritical water allow it to act as a media in which organics and oxygen can mix freely. The extreme conditions that form supercritical water (630°K, 250 atm) also induce complete combustion of the organics. Virtually all organics break down and reform into CO_2, H_2O, and N_2. Inorganics form salts which are less soluble in supercritical water than in water at its natural state. Invariably, the inorganics precipitate out. This paper will explain how technology based on these phenomena can be used in an ECLSS for CO_2 removal, partial humidity control, trace contaminant control, water reclamation, N_2 generation, and ultimately trash reduction. Then a qualitative comparison between an ECLSS with this SCWO technology and one of the Space Station ECLSS concepts will be given. Mass balances are included to enhance the comparison.

The SCWO technology simplifies the ECLSS by eliminating several of the Space Station ECLSS subsystems. The simplified ECLSS is less sensitive to production and consumption rates of potable water. Furthermore, inherent in the simplified concept is the potential for eliminating problematic cryogenics and high-pressure gaseous storage (the form of nitrogen supply considered for the Space Station). Other advantages of the new concept are discussed, and additional quantitative studies are recommended to increase confidence in supporting the development of SCWO technology and its application to ECLSS.

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METABOLIC SUPPORT FOR A LUNAR BASE

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A review of the metabolic support systems as provided in the past and ongoing space programs will be presented. This will permit the audience to become familiar with the constraints and requirements of space flight and the existing technology as these relate to metabolic support of astronauts. This information along with a general review of the NASA effort to develop Controlled Ecological Life Support System (CELSS) technology will support the definition of a generalized scenario of metabolic support for a lunar base. A phased program of metabolic support for a lunar base will be elucidated. Included will be specific discussion of the CELSS water reclamation and food recycle technology as it exists and how it could be expected to be progressively incorporated in the lunar base. This would be from a relatively open system in the initial phase when mechanical phase change water reclamation and minimal plant growth are incorporated to the final phase when practically total closure of the life support system will be provided through physiochemical and biological processes. Finally, a review of the metabolic intake requirements for the occupants of a lunar base will be presented.

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INTENSIVE FOOD PRODUCTION SYSTEMS FOR A LUNAR BASE STATION.

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On Earth the most productive agroecosystems include an ecologically balanced and thermodynamically favorable mix of biochemical, pattern, and species diversity within each system. Intricate (but simple) waste recycling loops and concomitant detrital food webs, closed mineral cycles, and well developed internal symbioses with redundancy further characterize these stable and high yielding systems. Development of a closed lunar agroecosystem must include these principles to attain the goal of a sustainable system.

It is argued that the most precious commodities in agriculture are water and fertilizer. In this regard a lunar agriculture could be simultaneously watered and fertilized by closely associating agriculture operations to intensive aquaculture systems using modern technology of screening, drip irrigation, aeroponics, hydroponics, and recycling polished water to aquaculture systems. For example, a number of intensive polyculture (mixed species) aquaculture systems (sized to the protein needs of the lunar colony) could produce fish, shrimp, and algae in each subunit. These systems could be fed by both the waste carbon dioxide from the human living areas and by sterilized human excreta. The aquaculture systems would, in turn, produce large quantities of oxygen, protein, and fertile waters. These fertile waters would be utilized in aeroponics, hydroponics and intensive drip-irrigated row-crop or raised-bed agriculture.

Similar existing systems on Earth have yielded in excess of one million pounds of combined fish, algae, shrimp, and vegetables per acre per year on a sustained basis. Examples of these are reviewed and a discussion of the merits of integrated solar energy/aquaculture/agriculture systems developed.

LIVING ALOFT: HUMAN REQUIREMENTS FOR EXTENDED SPACEFLIGHT

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ABSTRACT NOT RECEIVED IN TIME FOR INCLUSION

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Monitoring of the lung, heart, liver and brain can be accomplished with a biomagnetic sensor. This equipment uses semiconductor technology having low power consumption. Presently it is a complimentary tool to EEG and EKG. The sensor has the great advantage of non-invasive diagnosis of the liver, lung, heart, and brain functions. This non-invasive sensor makes diagnosing the human body simpler. It can use telemetry as in EKG and be operated by non-professionals.

The technical areas where this method can compliment the moon base includes: 1) Health and medicine; 2) Human functions/performance; and 3) Scientific study of the low magnetic field environment.

Specific areas which can be addressed are: 1) Lung contamination from dust; 2) Physiological health by brain monitoring of vision, hearing and touch; and 3) Psychological health. In the earlier phases of the moon base multiple arrays could transmit brain, heart, liver, and lung information back to the space station. In later phases equipment could be located on the moon base addressing human performance.

A LIVING SYSTEMS ANALYSIS OF SPACE HABITATS

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When we envision long duration extraterrestrial stays of human beings, we must plan for quite different social phenomena than have been seen in space missions up to now. With the exception of those missions in which astronauts have lived on space stations for periods of a few weeks or months, human extraterrestrial activities have been brief. They have required daring and initiative of carefully selected and highly trained astronauts specially equipped to accomplish the limited goals of those missions. When we think of the much lengthier stays required to provide a permanent human presence in space, it is clear that many aspects of life will have to change. Working and living conditions which are inconvenient, difficult, or uncomfortable can be endured on brief missions by highly motivated, trained professionals, as they are in crowded submarines or on arctic or antarctic bases. Months or years in in such circumstances, however, are another matter. Motivation gradually diminishes and discomforts become hard to endure. If men, women, and perhaps even children live together in extraterrestrial locations which, even with excellent communications to Earth, are inevitably isolated from the rest of mankind, their behavior will undoubtedly be different from any that has so far been observed in space. A new culture may well arise. It is not too early to begin systematically to try to understand what such habitats will be like in order to make better plans for them.

General living systems theory provides one possible approach to such analysis. This theory is a conceptual integration of biological and social approaches to the study of living systems. It emphasizes hypotheses about such systems that can be supported or refuted by scientific research.

The general procedure for analyzing such systems is to map them in two- or three-dimensional space. When the flows in them of matter, energy, personnel, communications, and money have been identified, gauges or sensors can be placed at various locations throughout the system to measure each of these flows and provide monitoring information to the inhabitants and to others about the processes of the total system so that its management can be improved (management information system) and its activities made more satisfying to the humans who live in it, as well as more cost-effective.

A program of such studies is needed that will aid in the design of space habitats. The first such research could investigate behavior in the space station simulator. Later, such analysis could also be made of the interactions between the people in Mission Control and those on an extraterrestrial space station. Other studies could be made of people living at bases in particularly severe Earth environments, such as Antarctica. From data collected in all these situations extrapolations could be made to other organizations in different extraterrestrial environments--the first small group on the Moon, a large, stable settlement of the Moon, and later an outpost on Mars or one of its moons.

LUNAR BASE: LEARNING HOW TO LIVE IN SPACE

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Human experience in space has so far been largely limited to small, homogenous groups of highly trained persons who---with the notable exception of Apollo astronauts and some contemporary cosmonauts---have not strayed far from Earth or stayed away for very long. Yet, a case can be made that some time in the future people will permanently live and reproduce in space---that communities of men, women and children, indeed whole new cultures and civilizations, will one day be located off Earth. This paper suggests that the establishment of a permanent lunar base would form a crucial step in learning how to live in space---in bridging the gap between current experience and future possibilities.

But establishing a permanent lunar base will not be easy. In addition to problems that must be solved in propulsion systems, habitat construction and life support, there is the challenge of how to organize and manage the crews that will actually pioneer living on the Moon. Proven procedures developed for relatively small groups of astronauts and specialists sent out on short-duration missions need to be expanded upon because lunar base crews: 1) are likely to become significantly larger and more heterogenous (in occupation, public/private status, sex and nationality); 2) will probably spend considerably longer periods in cramped and isolated quarters separated from Earth, family and colleagues; 3) will need to become more autonomous and self-managing both because of communication and logistics constraints and the need to further the goal of increasing self-sufficiency of the lunar base itself.

To plan this transition a systematic research and development program on crew composition, organization and management is proposed. The program would build on previous experience and relevant research, and should be integrated with related space station activities. It would involve realistic simulation experiments performed on the ground in mock-ups in order to develop models for crew structures, followed by the testing and refinement of those models first in the space station, and then on the lunar base itself. Crew personnel would participate more as co-investigators than as subjects, both to avoid alienation and to profit from their motivation and insights. The ultimate goal would be a harmonious and effective crew structure that would facilitate the achievement of mission goals, maximize the well-being and safety of the crew members and build a secure foundation for future communities in space.

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Abstract

Precedents for a Lunar Base Architecture: Implications For Human Factors Research

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This paper begins by addressing the question: Do lunar base conceptual proposals to date demonstrate a significant preference for any particular site, architectural form or organization? A search has been conducted of lunar base literature to sift out prototypes and paradigms for assembly or construction on the moon. These concepts for lunar work and habitation environments were compared for function, site selection, and transportation criteria. This line of investigation yielded the conclusion that lunar base architecture has not matured to the point where it is possible to generalize about "building types," preferred sites or optimal modes of transport.

This finding is important because it indicates that future design concepts for a lunar base should not be prejudiced by existing proposals. Each of the three areas of comparison (function, site selection, and transport system) suggest two similar implications for future research. These implications derive from the observation that none of the studies reviewed considered terrestrial analogs and precedents for a lunar base.

The first research implication is that the transportation system and site selection for a lunar base are linked in a mode similar to the transport and location studies carried out by economic geographers on earth. Generally the existing studies all assume one given transportation system such as Apollo and the Saturn 5, or modules carried to Low Earth Orbit in the STS Orbiter and then ferried to the moon. No rigorous study of lunar transportation systems and functions, unprejudiced by the transport system has been done to date. This finding suggests that an objective, economic geographical study of the entire STS - Space Station - Lunar Base - Transorbital Vehicle - Martian Base ensemble would be immensely valuable to lunar base concept development. Examples of economic geography methods will be presented. The lunar base as economic unit will raise profound human factors issues.

The second research implication is that none of the existing lunar base studies contain much substance on the relationship of function and form. This deficiency is partially the result of a lack of well defined missions or functions for a lunar base. The other cause of this lack is that these studies have not looked at functional precedents on earth for the lunar base. This finding suggests that an architectural/functional study of planned towns, ideal cities and intentional communities on earth would be an essential research endeavor, comparable to recent studies of space station analogs on earth such as antarctic bases and submarines. Examples of earth precedents for a lunar base will be presented. The lunar base as a complete, planned community with an architecture that grows from its social and economic functions will raise fundamental social science questions.

A LUNAR CITY: AN OVERVIEW

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The initial settlement on the Moon should be established with long term goals of growth into a permanent and self-sufficient colony or city system.

The establishment of a city does not necessarily mean that a large population is required. A mere increase in the number of people will not turn a base into a city.

It is the socio-economic and political system that makes a city a dynamic and growing entity. An independent and permanent Lunar Colony/City will only be established successfully with the cooperation and alliance of the private sector, the scientific community, and government agencies, just as it occurs in successful communities on the Earth.

From this point of departure I will describe the physical and social characteristics and relationships of the five major entities of the lunar community.

The Port: as the gates of the medieval walled cities.

The Industrial Park: as the income producing entity of the modern city.

The University/Research Center: as the driving force in the pursuit of truth, and the progress of mankind.

The Civic Center: as the support and coordinating government entity.

The Community Center: as the suburb of the modern city.

References:

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LUNAR BASES AND EXTRATERRESTRIAL LAW: GENERAL LEGAL PRINCIPLES AND A PARTICULAR REGIME PROPOSAL. C.C. Joyner, George Washington University, Washington, D.C. 20052 and H.H. Schmitt, P.O. Box 8261, Albuquerque, N.M. 87198

Extraterrestrial law, or space law, has become a recognized and indeed vital branch of international law. At least four major multilateral treaties affecting the conduct of states in outer space have been negotiated and are now legally in force. As a direct consequence, at least five fundamental principles of space law can be distilled and crystallized from their operative provisions : (1) Space, including the moon and other celestial bodies, is the province of mankind and should be developed for its benefit; (2) Space, including the moon and other celestial bodies, should be free for exploration and use by all states. Equality in and free access to all areas shall be available to all states, and freedom of scientific investigation shall be ensured to any interested party; (3) Space, including the the moon and other celestial bodies, is "not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means;" (4) Space, including the moon and other celestial bodies,shall be used exclusively for peaceful purposes;and (5) International law as formulated here on Earth does extend extraterrestrially to space, the moon and other celestial bodies. Relatedly, the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (the "Moon Treaty") attempts to define the moon's legal status as being the "common heritage of mankind." Close analysis of this concept reveals, however, that at present it fails to constitute a precept that is sufficiently normative in character so as to be considered a valid principle of international law. Today, the moon is <u>not</u> legally part of the " common heritage of mankind," although possibly it could be deemed so at some future time.

Existing international space law, as well as the best interests of all nations, is consistant with the establishment of a user-based international organization, INTERLUNE, for "the provision of lunar base facilities, services and access of high functional potential, quality, safety and reliability to be available on an open and non-discriminatory basis to all peaceful users and investors." Through an Assembly of Parties, a Board of Governors, a Board of Users and Investors, and a Director General, INTERLUNE would operate to meet its primary goals. The internal structure and philosophy of INTERLUNE provides for all participants to have representation in decisions affecting its activities, with the insurance of effective and responsive management. INTERLUNE essentially inculcates a model organizational concept tailored to provide cooperative management of a lunar base to the benefit of its members, users and investors. Most importantly, INTERLUNE would provide such management through sharing international opportunities, rather than through unilateral control by any one nation or set of competing nations. Surely this embodies a laudable precedent for mankind to follow as we embark upon a new era of outer space exploration.

Technological Breakthroughs and Space-Based Macroprojects: Opportunities for Collaborative Development

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Numerous technologies must be developed or advanced prior to initiating any lunar or other space-based projects. NASA, alone, does not have the financial, manpower, or other resources to undertake the required massive research and development program. This paper will identify opportunities for effective public and private sector collaboration to realize NASA's long-term goals.

BUDGETARY FEASIBILITY OF A LUNAR BASE

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ABSTRACT NOT RECEIVED IN TIME FOR INCLUSION

A DEBATE CONCERNING THE MERITS OF COMPETING INTERNATIONAL LEGAL FRAMEWORKS GOVERNING THE UTILIZATION OF LUNAR RESOURCES

Art Dula* and Herb Lingl**

An important factor in the calculus of making a commitment to expend capital to exploit lunar resources will be the legal regime governing how ownership of lunar resources is established. The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies[1] (the "Moon Treaty"), which has not been ratified by the United States or any other current space power, but which entered into force on its own terms with Austria's ratification of the convention, is an effort to establish such a regime. This debate will explore (a) the relative merits of the legal regime to govern lunar resources envisioned by the Soviet Union and certain developing states and a legal regime based on the principles underlying the predominately market based free enterprise economies of the Western states and (b) the differing interpretations of the Moon Treaty that advocates of these regimes have proposed.

The legal framework espoused by the Soviet Union and certain developing states is that lunar resources are to be exploited on the basis of the principle that such resources are the common heritage of mankind. Mr. Dula will argue that this legal framework is the most feasible, structurally sound and economically efficient legal system upon which to base the development of lunar resources. He will argue that lunar resources should be shared equally by all nations on the basis of a regime incorporating the one nation one vote principle. A licensing and resource allocation authority should be created to deed title and transfer technology in a manner analogous to the contractual regime envisioned by the Third United Nations Convention On The Law of the Sea.[2]

Mr. Lingl will argue that the legal framework for the exploitation of lunar resources should be based on the principles contained in the legal systems of capitalist free enterprise economies. He will argue that a legal framework based on these principles will enable the creation of a more flexible, structurally sound and economically efficient legal system upon which to base the development of lunar resources than the framework proposed by the Soviet Union and certain developing states. It would be economically inefficient to create a regime under which an international regulatory institution requires the execution of contracts providing for the transfer of technology and other assets as a condition to obtaining valid title to lunar resources, and such a regime would stifle the use of lunar resources for the benefit of humanity.

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[1] U.N. Doc. A/34/664, November 12, 1979, also reprinted in 18 INT'L LEGAL MATS. 1434 (1979).

[2] U.N. Doc. A/Conf/62/122, October 7, 1982.

REVIEW OF THE LUNAR ATMOSPHERE, PLASMA AND FIELDS: IMPLICATIONS FOR MANNED ACTIVITY AND FUTURE SCIENCE

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We present an overview of the space environment of the Moon, at the surface and in the immediate lunar vicinity. We describe the major features of the lunar atmosphere and ionosphere, the electrically charged surface and dust, the electric and magnetic fields at the surface and around the Moon, and the ionized plasma and energetic particles that impact the Moon. The effect of this environment on manned operations, and conversely man's impact on it, are discussed. We conclude with a survey of some possible future research directions utilizing a manned lunar base.

The Moon in its orbit is exposed to the flowing plasma and associated electric and magnetic fields of the solar wind; in addition, solar flares and galactic cosmic rays can be encountered. The Moon also passes through the confined plasma and fields of the extended tail of the Earth's magnetosphere, though magnetic storms and encounters with rapidly moving plasmoids make this region much more dynamic than originally anticipated. The intense solar spectrum of visible light and variable UV and x-radiation completes the external environment.

The Moon has a thin, tenuous atmosphere, consisting mainly of noble gases, due to accretion of solar wind and outgasing from the lunar interior. The atmospheric density is determined by complicated source and loss mechanisms, including solar wind impact as well as acceleration and ejection of ions by electric and magnetic fields in the solar wind and at the lunar surface.

Electric fields at the lunar surface are due to a surface potential generated by a balance between local charging processes which include photo- and secondary ionization and incoming plasma fluxes. Resulting lunar surface potentials are expected to range from +5 to +10 volts on the dayside and -10's to -100's of volts at the terminator and on the nightside.

Finally, man's presence in this lunar environment is discussed. Some possible environmental hazards, such as electrostatic coating by dust, to manned activities and effective scientific experiments, are mentioned. Conversely, factors that will be critical to possible damage to the lunar environment, such as atmospheric contamination, are presented. We conclude by suggesting some fundamental scientific research possibilities at a lunar base, for example: long-term measurements of Sun/Earth interactions including the solar constant, planetary studies such as imaging the Io plasma torus and possible aurora on Uranus, active plasma and critical velocity experiments, and research with possible cosmological significance such as studies of dusty plasmas.

STUDIES OF THE GEOMAGNETIC TAIL FROM A LUNAR BASE,

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The solar wind, a fully ionized hydrogen plasma flowing continually from the sun, impacts the earth's magnetic field, compressing the sunward portion of the field and stretching its anti-sunward portion downstream to form a comet-like structure, millions of kilometers long, called the geomagnetic tail or magnetotail. The cavity in the solar wind that contains the greatly distorted geomagnetic field is called the magnetosphere. In its interaction with the solar wind the magnetosphere gains energy and plasma, some of which it dissipates to the earth and to space around the earth by various means, some of which impact upon man's activities. For example electric currents are driven through the ionosphere perturbing the geomagnetic field, heating and perturbing the ionosphere, and altering thermospheric wind patterns. Particles are energized to form the earth's radiation belts; some of these particles precipitate into the atmosphere altering its chemistry and producing the polar auroras. A large fraction of the acquired energy and plasma is returned to the solar wind in the form of large bodies of magnetized plasma, called plasmoids, that are created by magnetic reconnection during substorms and flow swiftly downstream through the tail. The moon, crossing the magnetotail 360,000 km from earth every month, constitutes an excellent platform from which to study the structure and dynamic processes of the magnetotail. The moon has already been used very successfully in this capacity, both for experiments based on the lunar surface and for experiments on a satellite orbiting the moon. Problems are, of course, presented by the moon's large size, obstructing fields of view of various detectors, and by the particle, electrical and magnetic contamination it imposes on the environment. But these are far outweighed by the high degree of sophistication, e.g., in experiment size, multiplicity, complexity and personal attention that a lunar base will permit. Some experiments that would become possible, for example, are (1) large and diverse detector arrays to study magnetotail boundary structure and motions; (2) relativistic electron beams to trace field lines and measure convective motions; (3) visual or photographic observations of plasma convective motions (e.g., plasmoid departures) through the tail. Opportunities and problems of lunar basing such advanced experiments will be discussed.

COSMOCHEMISTRY AT THE LUNAR BASE: PASSIVE COLLECTION AND ISOTOPIC ABUNDANCE DETERMINATIONS OF SOLAR, METEORITIC, COMETARY AND INTERSTELLAR MATTER

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Among the more important scientific investigations, which require lunar base facilities, are studies regarding the chemical and isotopic compositions of ions, gas and dust particles in the solar system. The superior vacuum of the moon permits appropriate passive collectors to be set up and operated at a lunar base.

Solar Wind and Flares: The solar wind composition experiments on the Apollo missions demonstrated the feasibility of passive collection for measurements of the isotopic abundance of He and Ne in the solar wind. Similar controlled long-term collection experiments will provide information on additional important elements, as well as on temporal fluctuations in flux and composition. Of particular interest is the isotopic composition of nitrogen, since this element is unique among trapped gases in lunar fines in exhibiting variations at the 30-40% level. Nitrogen isotopic analyses at the lunar base would substantially reduce system blank problems which currently limit the sample size in static mass spectrometer analyses of N in terrestrial laboratories. Solar flares particles, which are known to be variable in composition, can be separated according to energy (penetration depth) and their temporal variability and long-term average composition investigated. The mechanisms responsible for their elemental and isotopic peculiarities and the relationship to the solar wind and to the solar photosphere are ill understood at this time. This information is required for an understanding of the origin and evolution of planets and planetary atmospheres. Special detectors may allow to monitor lunar outgassing and to discriminate the retrapping of lunar ions and interstellar gas.

Micrometeorites, Cometary Particles: It is generally recognized that studies of micrometeorites, of cometary material and of any interstellar dust are essential for our understanding of the origin of the solar system, of element synthesis and the evolution of the interstellar medium. A preliminary design of a suitable collection and analysis facility is the following: Large area passive detectors consisting of several foil layers with sealed volume chambers permit particle tracking, impact-vaporization and isotopic analysis of the vapor phase for H, He, C, N, O, Ne, Ar, Kr and Xe by static mass spectrometry. The number and size of detectors can be selected to allow for one or more analyses per day. Periodic analyses of the residues in the impact pits may yield information on the chemical composition of the impactors. Periodic repairs of the impact perforations will be required. The orbital origin of each particle, as obtained from recorded direction and selenocentric velocity determinations, can be correlated with the information on volatile abundances and isotopic signatures. The volatiles are collected by cryogenic techniques and separated by techniques which are being or can be developed. Isotopic analyses are then carried out by high-sensitivity static mass spectrometry of atoms or molecules, or both, if feasible to increase the stored information content. Future refined experimental techniques may allow analyses of nanogram-sized particles. The relationship between cometary and interplanetary matter is not known, but some evolution during the time since the solar system formed is expected. We want to stress that passive collection and study of cosmic dust complements, rather than substitutes for missions to comets and asteroids because a wide spectrum of matter can be sampled.

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BASIC CRITERIA FOR THE SECOND GENERATION GEOPHYSICAL EXPLORATION OF THE MOON

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Geophysical exploration during the Apollo missions showed that the Moon was seismically active, that the surface was endowed with local and regional magnetic fields, and that the interior was directly accessible to both seismic and electromagnetic exploration. Nevertheless the major questions regarding the Moon's origin and evolution remain unclear. These include its formation, thermal history, and present internal structure. From experience in the Earth sciences, it is possible that a long time and the development of an extensive data base will be required. The Apollo geophysical program made use of fixed station (ALSEP) instruments, the rover, and orbiters (Apollo subsatellites). The distribution of seismic stations was restricted by system energy constraints, so that the network could only marginally, at best, observe wave shadowing. A second generation system should be more widely spread and include antipodal observations for large impacts, to optimize detection of a liquid core. At the same time array size should take cognizance of directional sensitivity. Magnetometer observations should be long term and of high stability. Surface only measurements are restricted to low order multipoles of the field, but core detection only requires the dipole. Extended traverses closely coordinated with geology are required to map the permanent fields. But this requires a baseline magnetic system to zero out the variable field of the solar wind. Heat flow measurements are essential but the most difficult to properly site and may require a large number of emplacements. The Moon's plasma environment is dominated by the solar wind which directly impacts the surface. Monitoring of the solar wind including composition, physical parameters, electric and magnetic fields is required to obtain a more complete data base for the lunar plasma environment. Geophysical research can effectively make use of all perceivable modes of emplacement, fixed station arrays, orbiters, local and regional traverses, and penetrometers. Use of these will probably have to be closely coordinated with other exploration objectives for cost-effectiveness.

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LUNAR SECONDARY PROJECTILE DETECTORS AT A LUNAR BASE

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When meteorites of any size hit the surface of the moon secondary projectiles are generated which consist mainly of lunar material and which may have a wide range of velocities. The mass of lunar secondary projectiles may greatly exceed the mass of the primary meteorite impacting material. The size distribution and velocity distribution of such secondary projectiles are not well understood. The flux, flux distribution, and velocity distribution of lunar secondary projectiles is not only scientifically interesting and important, it may also be an engineering parameter which must be taken into account in the design of structures and optical elements used at lunar bases.

Consequently an important experiment to be done early at a lunar base is to determine the properties of lunar secondary projectiles. Various types of impact detectors have already been designed for spacecraft experiments. It is possible to design a detector which can determine the size, velocities, and directions for micrometeorites hitting the detector surface. Such detectors could be deployed at a lunar base in various orientations and with appropriate collimation so that they only "see" selected; lunar features: mountains, crater walls, known surface areas, for example, as well as the open sky.

Data from these detectors could determine the proportion of the impacting flux in the vicinity of the lunar base which is primary and that which is secondary. Chemical analysis of residues in detector craters or surfaces could further help differentiate between secondary and primary particles. It might be possible, using composition data combined with trajectory data to determine the composition of the lunar surface at the source of the secondaries and to determine the location of the source with reasonable accuracy. This experiment would then be a remote sampling probe for various parts of the lunar surface. The detectors would probably have to be deployed at some distance from the main base to avoid contamination from dust generated by base operations but this distance would probably not be too great. Collimation would minimize material from the direction of the base.

Detailed data on the flux and flux distribution of lunar secondary projectiles will help fill in some important gaps in our understanding of lunar regolith dynamics and lunar regolith composition. Some important questions in regolith dynamics, such as whether agglutinates are transported as discrete secondary projectiles, might be answered. In turn, some of the data from this experiment will contribute toward our understanding of other solar system bodies and the collision dynamics of the early solar system when secondary projectiles may have played a major role. Additionally, the flux and velocity of secondary projectiles may be an engineering constraint on lunar base operations and exposed optical elements such as lenses and mirrors, and solar panels.

LAMPF EXPERIMENT E225: A SMALL, FINE-GRAINED NEUTRINO DETECTOR

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To provide a basis for symposium attendees to judge the feasibilty of placing a neutrino detector at a lunar laboratory, a current neutrino research program is presented. The program is being carried out at the 800 MeV proton beam stop of the Los Alamos Meson Physics Facility (LAMPF) by a collaboration from the University of California at Irvine, Los Alamos National Laboratory, and the University of Maryland. The experiment, E225, is designed to measure neutrino-electron elastic scattering and neutrino-carbon reactions, and to search for neutrino oscillations, neutrino decay, and axion production. Present considerations for using our experimental system as the core detector in an extensive-air-shower array, in order to be able to look at very high energy cosmic rays, will be discussed.

The neutrino detector has three main components: a central detector which is used to identify and record charged-particle tracks, a live anti-coincidence system used to veto (or identify) charged cosmic ray particles, and a passive shield used to eliminate hadronic and electromagnetic cosmic ray particles. The central detector consists of 14 tons of scintillation counters and plastic flash chambers arranged in 40 modules. Each module is composed of four scintillation slabs, each 76 cm wide, 305 cm long, and 2.5 cm thick, formed into a single 305 cm × 305 cm layer. The scintillator is followed by 10 layers of plastic flash chambers, with 520 tubes per layer, arranged with alternating horizontal and vertical tubes. The scintillators provide energy and energy-loss (dE/dx) information, and the flash chambers provide tracking information. Energy resolution from the scintillator is ±10%. Angular resolution from flash chambers is $\pm 7^{o}$ for short electron tracks, and perhaps as good as $\pm 0.2^{o}$ for long muon tracks. Our 18-ton live anti-coincidence system is composed of four layers of extruded-aluminum proportional tubes with a total of 4832 wires. These chambers are operated in a two-out-of-four coincidence requirement in order to achieve an inefficiency for charged particles of less than 2×10^{-5} with a dead time of less than 15%. A passive shield of about 2000 tons of steel, concrete, and lead surrounds the central detector and live anti-coincidence system.

Details will be given of the detector and of its performance. Examples will be shown of detector response to electron, muon, gamma ray, and hadron events.

PROPOSAL FOR A NEUTRINO TELESCOPE ON THE MOON

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Neutrinos provide unique probes of the energy generating processes in the centers of stars and of other basic stellar phenomena. Neutrino detectors on the earth are limited by the backgrounds of neutrinos generated in the earth's atmosphere by the decay of pions, kaons and muons that result from the interaction of energetic cosmic ray primaries. The large radial extent of the very low density upper atmosphere results in long absorption lengths, 10 km or more, for pions and kaons and thus permits a significant fraction of these particles to decay. These decays both give rise to neutrinos directly and produce muons that, in turn, either add to the neutrino background by decaying or penetrate deeply into the earth and thus force these detectors into very deep underground sites.

The absence of an atmosphere on the moon reduces this muon and neutrino background by at least 5 or 6 orders of magnitude. Only those leptons produced by "prompt" production processes would remain. Detectors a million times as sensitive as those on earth would be possible. They would only require burial by a few tens of meters, which could be achieved by shallow trenching, by bulldozing a mound above the detector or by a combination of these techniques. The detectors themselves are likely to be a combination of scintillation counters, either liquid or plastic, together with tracking devices. The technology for such instruments exists now, but the environment of the moon will pose special and possibly severe constraints on the specifics of such a detector.

We will present calculations demonstrating the increased sensitivity of such a detector on the moon vs. one on the earth, a possible scenario for the construction of such a lunar neutrino telescope and indications of the kind of astronomical objects that such a telescope might view.

HIGH-ENERGY NEUTRINO ASTRONOMY FROM A LUNAR OBSERVATORY

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The detection of high-energy (HE) cosmic and solar-flare neutrinos near the lunar surface would be feasible at energies lower than for a terrestrial observatory by at least two orders of magnitude, i.e., at 10^{10} eV. The main advantages at these energies will accrue from the decisive reduction in background—by a factor of > 10^{3}—below that expected for neutrinos generated by cosmic rays in the earth's atmosphere. Because of the short mean free paths (< 1 m) of the progenitor pi and K mesons against nuclear interaction, the neutrino background would be quite low. At 1 GeV, only < 1 per cent of the pions would decay; at 10 GeV, < 0.1 per cent. Thus, if the neutrino flux to be observed is intense enough, and its spectrum is steep enough, then the signal-to-noise ratio would be very favorable. It might be thought that the reduction in cross section at lower energies would cancel the advantage of enhanced flux. It can be shown, however, that for celestial sources generating a neutrino spectrum similar to that of Galactic cosmic rays, the cross section effect would be overcome. The observation of HE neutrinos from solar flares would be dramatically enhanced, especially at lower energies, since the flare spectra are very steep. Detection of these neutrinos on earth would not be feasible even with the best detectors thus far designed. Moreover, higher-energy neutrinos (> 10^{12} eV) that could, in principle, be detected are virtually absent from solar flares. A remarkable feature of solar flares as viewed in HE neutrinos from a lunar base is that the entire surface of the sun would be "visible". Indeed, flares on the <u>far</u> side of the sun would be producing more neutrinos moving toward the detector than those on the near side. Diffuse sources of HE neutrinos, such as the Galactic disc (especially from the Galactic center), would be detectable at energies between, say 10^{10} and 10^{14} eV. On earth, they are swamped by the overwhelming atmospheric background, so that their detection would be marginal. In contrasting HE neutrino astronomy on the moon with that on earth, it seems natural to use, as a basis of comparison, the only HE neutrino observatory that has been designed in detail, i.e., the DUMAND array. This undersea detector will have an effective energy threshold not much lower than 10^{12} eV.

PRELIMINARY DESIGN OF A PERMANENTLY MANNED LUNAR SURFACE RESEARCH BASE

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ABSTRACT

A brief study has been performed to assess the advantages and/or disadvantages of a Lunar-Surface Space Base for civilian research and development with and without a comparable low-Earth-orbit Space Station. The suitability of undertaking scientific investigations in the diverse fields of astronomy, high-energy physics, selenology, planetary exploration, Earth science and life sciences was considered for both bases. A set of Lunar Base science experiments was found to be largely separate from and complimentary to Space Station science. Since the science best performed at either base was largely complimentary, rather than competitive, both initiatives bear serious consideration.

A Lunar Base was conceived to conduct the identified science, along with transportation requirements to establish and support continued operations at the Base. A ROM estimate of the cost to deploy and operate the Lunar Base for a period of three years was made. This estimate was made with and without a low-Earth-orbit Space Station serving as a transportation node. Starting with the Space Station will assure performance of important low-Earth-orbit science, and would also set in place certain elements of the transportation infrastructure found necessary to deploy and sustain a lunar base at a reasonable cost level. It is concluded that the Space Station will best serve near-term objectives and provide more immediate benefits. Additionally, it is suggested that a Lunar Base be given serious consideration as a longer term goal of Space Policy, capable of providing important direction to the Space Station initiative.

IMPACT OF LUNAR AND PLANETARY MISSIONS ON THE SPACE STATION, G. R. Babb, H. P. Davis, P. G. Phillips, and W. R. Stump, all with Eagle Engineering, 17629 El Camino Real, Houston Tx, 77058

The impact upon the growth Space Station of several advanced planetary missions and a populated lunar base is examined. Planetary missions examined include sample returns from Mars, the comet Kopff, and the main belt asteroid Ceres, a Mercury Orbiter, and a Titan Probe/Saturn Orbiter. A manned lunar base build-up scenario is defined, encompassing preliminary lunar surveys, ten years of construction, and establishment of a permanent 18 person facility with the capability to produce oxygen propellant for use in space.

The spacecraft mass departing from the Space Station, delta V requirement, and scheduled departure date for each payload outbound from low earth orbit, are determined for both the planetary missions and for the lunar base build-up. Large aerobraked Orbital Transfer Vehicles (OTVs) are used, similar in concept to those now being designed for geosychronous orbit missions. Two 40 metric ton propellant capacity OTVs are required for each of the 70 lunar sorties in the base build up scenario. The two most difficult planetary missions (Kopff and Ceres) also require two of these OTVs. The vehicles sized for lunar vicinity transport have the capability of delivering about 18 metric tons to the lunar surface. Other lunar transportation elements needed to execute the scenario include an expendable lunar lander, personnel modules for orbit transfer and for lunar landing, an expendable lunar ascent stage, and a reusable lunar lander which will use lunar produced oxygen.

Impacts upon the Space Station from operations including propellant loading and storage, mating of OTVs and cargos, flight vehicle checkout and repair, warehousing, and quarantine and handling of returned planetary samples are studied. For the lunar base, the Space Station must provide at least two non-pressurized OTV hangers, and personnel and equipment to support an average of 14 OTV launch, return, and refurbishment cycles per year.

The Shuttle only, and Shuttle plus Shuttle Derived Vehicle (SDV) launch load and rate requirements are determined in order to support the scenario assumed. An average of 560 metric tons per year must be launched to the Space Station for lunar base support during the ten years of base construction. Approximately 70% of this cargo from Earth is OTV propellant. An unmanned SDV capable of lifting 100 metric tons is considered necessary to deliver this propellant. An average launch rate of one Shuttle every two months and one SDV every three months to the Earth orbit growth Space Station will lift the required 560 metric tons per year.

A COMPARISON OF CONVENTIONAL TRANSPORTATION TO GEO AND LUNAR ORBIT WITH TRANS-GEO-RENDEZVOUS (TGR) AND TRANS-LUNAR-RENDEZVOUS (TLR) CONCEPTS

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Transportation that is flexible and dynamic has been characteristic of America's history and has provided great impetus to progress. Our nation has witnessed great growth as the result of clipper ships, railroads, automobiles, the DC-3, merchant ships, interstate highways, and jet aircraft. The new ocean of space above the atmosphere awaits exploitation.

The permanent manned presence of America's space station is presently slated to be frozen in a low inclination orbit for the purpose of enabling outer space accessibility. The assumptions basic to this are that the crew modules (CM) and the orbital launch facility (OLF) must be either attached or in close proximity, and that space based delivery systems to outer orbit requires extensive operations.

If the space station CM and the OLF are considered as separate entities and the OLF located in an optimum low inclination orbit, the following advantages can be realized:

1. The permanent manned presence of the CM can be accessible to launch complexes at VAFB in addition to KSC (in low inclination orbits rescue could not be accomplished from VAFB).

2. A high inclination space station CM could eliminate the need for an additional orbit station as indicated in some NASA advanced plans.

3. A space station CM overflying all of continental United States, plus Europe, Asia, and South America, would expand U.S. public support and encourage strong foreign contributions (thereby freeing U.S. efforts to develop timely leadership in outer space transportation).

4. Soviet launch sites would be able to reach our space station CM opening an opportunity for realistic cooperation.

The purpose of this paper is to present an evolutionary scenario of missions utilizing trans-destination-transfer of payloads from departure propulsive stages to an arrival stage that will constitute a reusable transportation system to and from geosynchronous and lunar orbit. Trade studies comparing TGR-TLR with various conventional methods include: 1 and 2 stage LEO departures, aerobrake parameters, stay times, refueling requirements, orbital assembly complexity, plane changes, lunar surface accessibility, and growth potential. The significant performance gains inherent in a zero OLF (direct assembly and LEO departure) is clearly demonstrated.

This improved insight of future outer orbit missions allows reaping potential benefits of higher inclination space station CM assemblies.

LUNAR LOGISTICS DURING THE FIRST HALF OF THE 21st CENTURY

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The first phase of lunar exploration was concluded in the early Seventies with the end of the APOLLO program. The exploitation of lunar resources is bound to come, probably around the turn of this century. However, the space transportation system (STS) we know will not be good enough (2000 kg payload for \$ 100 x 10^6). We have to develop a "Heavy Launch Vehicle" (HLV) using Shuttle hardware to make it soon and cheap.

This paper shows that, short of availability of lunar polar ice, there is no better way (sooner or cheaper) that to use LH_2/LOX propellants and a fully reusable space transportation system derived from hardware (SSME and tanks) of the STS. A lunar factory to produce lunar oxygen is the key to an efficient lunar logistic system, particularly if lunar products are to be transported from the lunar surface to the geostationary orbit e.g. for the construction of Solar Power Satellites (SPS).

The backbone of the lunar transportation system proposed here is a ballistic, fully reusable three-stage launch vehicle with a take-off mass of 7 000 Mg and a lunar bus between lunar orbit and lunar surface with a take-off mass of 500 Mg. All stages use the SSME at 100% thrust level. We also need a space operation center in lunar orbit for refueling and maintenance of all ferry vehicles. This manned satellite has an empty mass of about 300 Mg. The cost of operation is primarily a function of the life cycle duration (assumed to be 50 years) and the launch rates, or payload mass, transported annually. The vehicle proposed has a payload capability of 85 Mg from earth surface to GEO or lunar orbit. The lunar bus, refueled in lunar orbit, takes three 85 Mg payloads down to the lunar base during each flight, when required.

The specific transportation cost of this lunar logistic system is down to 3000 \$/kg to lunar orbit at an annual volume of 10^3 Mg and are only 500 \$/kg at an annual volume of 10 x 10^3 Mg. Only five percent has to be added to these cost figures for getting the payload down to the lunar surface because lunar LOX is used! At these transportation costs we can afford a rather suitable and comfortable lunar base!

It is also shown that all other propulsion systems, such as electrostatic solid core or gas core propulsion systems are less economical and inferior from the operational point of view to high performance chemical propulsion systems using lunar LOX.

To exploit the lunar resources we do not have to wait for advanced technology; all we need is to develop a Shuttle-derived Heavy Launch Vehicle which can be done within 7 years for the price of about 20 x 10^9 dollars. It is about time to develop a detailed project plan to assist in the decision making process.

LUNAR BASE DEVELOPMENT: A SPSS SCENARIO

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A lunar base is bound to be developed sometime early in the next century. However, this base needs a logistics system that is much more efficient than the present STS. A "Heavy Launch Vehicle (HLV)" derived from Shuttle hardware is the most likely candidate.

Such a development, however, will be initiated only if there is a requirement. This requirement can be developed from scientific and political motives or from commercial needs. There are two potential customers:

(1) extraterrestrial storage of high energy nuclear waste

(2) construction and operation of a Solar Power Satellite System (SPSS).

At the present time, both of these potential markets do not appear to be in the category of a high priority. One of the reasons is that the reference systems for detailed mission analysis chosen so far have not shown favourable results.

With the insight available today, these reference systems can be improved considerably and should be updated! This study shows clearly that a GEO and lunar logistics system based on SSME technology using lunar LOX and lunar manufacturing can offer great advantages which make a combined market of a SPSS (with 100 5 GW units) and a lunar deposit for high energy nuclear waste an attractive proposition. A detailed mathematical simulation model was developed comprising about 250 equations and 500 variables to analyse the growth pattern of a lunar base. This is the most comprehensive lunar base model published up to date. It is shown that during a 50 year life cycle a lunar base (to become operational in the first decade of the next century) can serve these markets efficiently. A lunar base with a crew of about 600 people and a mass of 16 000 Mg at the average can produce stock and construction material at rates below 10 $/kg. In addition, about 50 $/kg are required for transporting these goods to a GEO construction site.

The lunar alternative reduces the logistics cost of SPSS to about 1/3 if compared with a solely Earth-based logistic system. This will probably make the difference whether a SPSS is economically competitive. It is concluded that a new SPSS system study with an updated logistic system and with the use of lunar resources is urgently needed.

TRANSPORTATION ECONOMICS OF LUNAR OXYGEN UTILIZATION IN LEO

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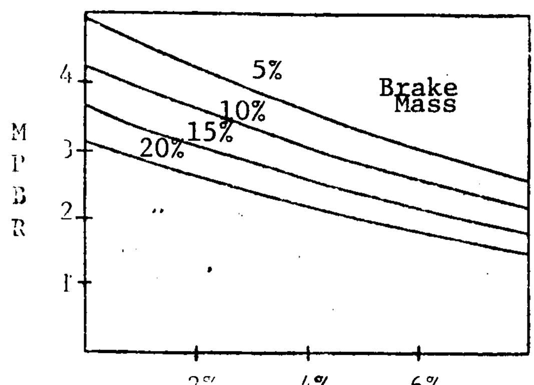
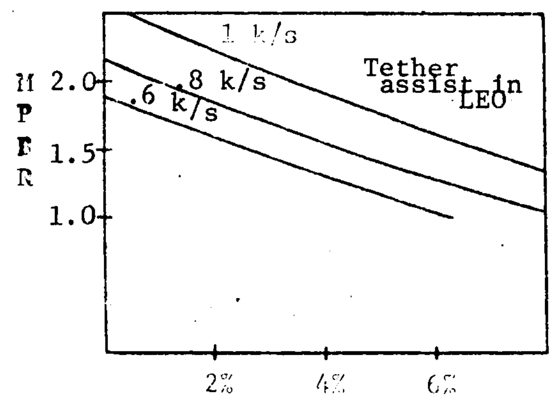
Oxidizer makes up a majority of the payload carried from the earth's surface to low earth orbit. With the advent of an OTV system, this oxidizer will be liquid oxygen. It is widely accepted that use of oxygen produced on the moon could greatly increase the effective lift capacity of the earth to LEO leg of the space transportation system under the right circumstances.

Several studies have shown that certain conceptual designs yield a net mass return substantially larger than the mass which must be delivered from earth to operate them. These studies typically incorporated several new propulsion technologies, did not account for the cost of emplacing the vehicles and storage depots, and considered the economics of single point designs, without examining the effects of varying parameters such as tankage, I_{sp} or aerobrake mass fraction about their nominal values.

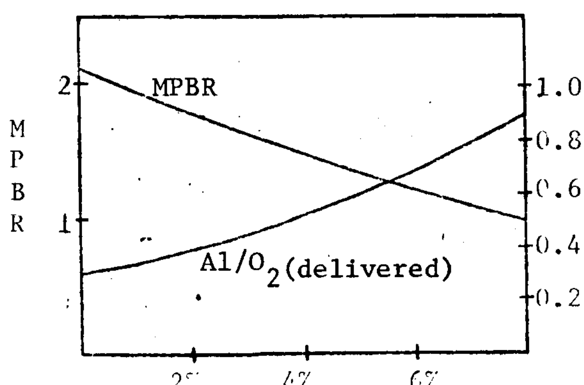
The transportation and emplacement economics of several different transport schemes are reported as a function of tankage and other appropriate variables in cases where only one new technology has been used in each transportation system. It can be seen that aerobraking is the most promising technology, and that optimal aerobrake design is not necessary to yield economical performance. Tethered boost and deboost of the translunar vehicle also leads to reasonable improvements in economy. Advanced hydrogen-oxygen engines do not. Use of External Tank derived aluminum to enhance the impulse available from the H - O propellant used in the translunar injection also enhances economics significantly.



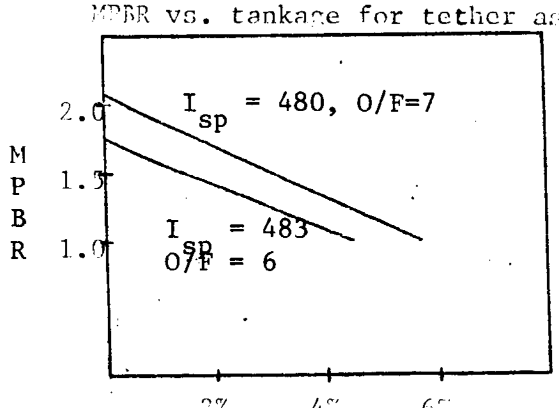
MPBR vs. tankage for aerobrake



MPBR vs. tankage for tether assist



MPBR and Al/O_2 vs. tankage for Al TLI burn



MPBR vs. tankage for new engine

ABSTRACT

A Comparison of Space Resource Options

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Three possible extraterrestrial resource production scencrios are described as follows: 1) Lunar oxygen propellant from the Moon as we know it, 2) Lunar hydrogen and oxygen propellant from plausible polar ice deposits and 3) Asteriodial radiation shielding. Each non-optimized operation is compared on the basis of onsite power requirements, breakeven mass throughput, and mass payback ratio to low Earth orbit. Capital mass requirements and the sophistication of required equipment are estimated, along with likely levels of automation, teleoperation, and crew involvement.

The potential market for each product and the exploration requirements for each scenario are reviewed from prior work. A brief comparison is made between ballistic and low thrust (solar sail or nuclear electric) returns from near Earth asteriods. The degree to which each operation may rely upon technologies and equipment developed for the Space Station and other programs is reviewed to derive a list of technologies for which need is relatively insensitive to the eventual selection of an initial space resource product.

TETHERED FACILITY FOR LUNAR MATERIAL TRANSPORT

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Tethers have been proposed for a number of applications, and theoretical analyses of their behaviour are underway in a number of areas. One of the interesting applications of tethers in space is that of a lunar-orbiting tether momentum transfer facility. Such a facility, for example, may consist of a large space station in circular orbit connected by a tether (cable), hundreds of kilometers long, for picking up and holding a payload. A certain point (close to the system center of mass) along the tether, would be in true orbital equilibrium, while the two end masses would be pulling on the tether. Now by swinging or spinning the tether and releasing the payload, we will be transferring momentum to the payload and can place it either in a different orbit about the same central body (here moon) or into an escape trajectory, say towards a Low Earth Orbit.

This type of facility is enabled by a space station tether technology base, and in turn benefits later phases of a long-term space station program. Such a facility might transfer payloads between the lunar surface, the facility itself and lunar escape trajectories without the use of rocket propellant. Such transport capabilities may justify the development of lunar space station as the initial focus of lunar industry. This obviates the need for a large prior investment in a fixed plant on the lunar surface, and hence might radically reduce the cost and lead time required to startup lunar industry. Two such tether facilities might be useful: one in equatorial orbit and one in polar orbit. The equatorial system would pass over every point on the lunar equator every orbit, while the polar system would pass over both poles every orbit (valuable if water is found there), and every other point on the lunar surface very infrequently (valuable for "prospecting"). The results of some studies underway at California Space Institute under NASA sponsorship will be presented here. These studies deal with the capabilities required by such tethered facilities (such as mass, power, thrusters to cancel perturbations) for them to be in either polar or lunar equatorial orbits.

ACHROMATIC TRAJECTORIES AND THE INDUSTRIAL-SCALE TRANSPORT OF LUNAR RESOURCES: T. A. Heppenheimer, Center for Space Science, Fountain Valley, CA

Electromagnetic mass-drivers may be used for transport of lunar resources to an orbiting industrial center. One transport mode calls for the mass-driver to launch bags of lunar material on unguided trajectories to a mass-catcher near the L2 libration point. Such trajectories are studied within the rotating coordinate system of the restricted three-body problem. This coordinate rotation gives rise to a focusing effect, whereby the payloads' aim can be made insensitive to errors in launch velocity. The trajectories' arrival accuracy, at the mass-catcher, can be proportional to the square of the launch velocity error, not (as is usual) to the first power of this error. Such trajectories are called "achromatic." A launch error of 1 cm/sec can produce a miss of 20 centimeters at L2, which is 64,000 km behind the Moon. (1)

During the first few tens of kilometers of their flight, payloads launched by mass-driver can be tracked; the errors in their three components of launch velocity can be detected and corrected. The preferred location for the launch site is at 33.1 degrees east longitude on the lunar equator. Topographic considerations shift this to nearby sites in the southern Mare Tranquillitatis, near the crater Censorinus. (1, 2) It appears possible to so adjust the payload trajectories, immediately following launch, as to achieve a circular error probable of diameter 3 meters, for a catcher near L2. (3)

The mass-catcher is proposed as a self-propelled rotating conical bag. Payloads break up on hitting the bag; their material forms a "catcher regolith" the formation of which can be studied using results from lunar regolith theory. (2) The catcher must maneuver during a lunar month, so as to follow the incoming mass-stream; this catcher motion can be optimized. The associated catcher delta-V is approximately 200 m/sec per month. (2, 4)

Once the catcher is full, its caught material can be consolidated and set in free flight from the L2 vicinity. It enters a transfer orbit that closely approaches several stable resonant orbits of Earth, these being possible locations for the space industrial center. The preferred location is at the 2:1 resonance; it has semimajor axis of 243,800 km, eccentricity of 0.4399. Consolidated material in the transfer orbit can be moved into the 2:1 orbit with a delta-V of 63 m/sec. (5, 6)

In addition to the mass-driver proper, then, a complete transport system for lunar resources may require the following: downrange stations to detect and correct launch errors (3, 7); a mass-catcher (2, 4); and a terminal tug, to shift consolidated material from the transfer orbit to the 2:1 orbit. (2, 5) The catcher and terminal tug appear to have similar propulsion requirements.

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ALUMINUM FUELLED SPACE ENGINES FOR ECONOMICAL LUNAR TRANSPORTATION

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The majority of the mass which departs LEO destined for the moon will be propellant. Any method of obtaining some of this propellant mass at lower cost than launching it as payload will greatly increase the economy of lunar exploration. Aluminum is likely to be a freely available commodity in LEO in the form of shuttle, SDV or HLLV tanks and expendable fittings. Addition of aluminum to a hydrogen - oxygen combustion mixture greatly increases the total impulse available in the system with minor penalties in I_{sp}.

Use of scavenged external tank aluminum to stretch the impulse available from scavenged residual hydrogen and oxygen is attractive. First, the H-O-Al engine will operate well at a mixture ratio of 1:3:3, using the hydrogen to oxygen ratio which will actually be available from scavenging. Second, the I_{sp} of the H-O-Al engine is expected to exceed 400, so use of the freely available aluminum fuel increases propellant availability from scavenging by 45%. Third, there is a great excess of aluminum relative to propellant needs, so it is always available to stretch cryogens brought up as payload.

The availability of an inexpensive fuel in LEO improves the economy of transportation systems delivering lunar oxygen to LEO, despite the lower expected engine impulse and the need for significant amounts of terrestrially derived hydrogen. This is due to two factors of similar importance. First, in most lunar oxygen delivery scenarios, much of the oxygen delivered to LEO must be burned to send hydrogen fuel to the moon. Aluminum can replace about half of this oxygen used in running the transportation loop, and thus make more oxygen available in LEO. Secondly, the oxygen delivered to LEO can be burned with aluminum, approximately doubling its propellant value. This halves the size of the oxygen producing and delivering system, and thus halves its emplacement costs.

LEO, LUNA, AND MARS

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In the coming Extraterrestrial Century permanent manned bases will be built in Low Earth Orbit (LEO), on the lunar surface, and on Mars. The lunar and martian bases will then evolve into self-sufficient settlements. A long range projection of these developments can provide a valuable perspective to support near term program decisions that greatly broaden NASA's long range options. For example, the LEO Space Station to be built in the next decade should be designed to serve as spacecraft assembly facility, maintenance and refueling base, transportation node, and Space Operations Center for the advanced space transport systems that will open access to cislunar space, the Moon, and Mars. Future manned and robotic missions to the Moon and Mars should be designed to the advance the date, and reduce the cost, of permanent settlement. Unlike terrestrial conquests, the conquest fo the Moon and Mars is not a "Zero Sum" game, in which my victories are your defeats; it is a victory for all mankind. This should greatly facilitate international cooperation.

To help develop a long range perspective this paper discusses likely political and economic developments on Earth that will support large multinational investments in space in the next century and then projects potential decade by decade milestone achievements through 2085 that will initiate man's evolution into the cosmos.

THE CASE FOR MARS

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Establishing a manned base on Mars is a logical next step in solar system exploration which provides a long-term focus for current and planned space program activities. The space transportation system, space station, and lunar base are all part of a space infrastructure that logically preceeds establishing a manned base on Mars.

Much of the technology development for the Lunar base can be shared with a Mars base effort including equipment for geoscience and network science, manned rover vehicles with/without life support capability, materials processing for obtaining metals and construction materials, underground habitat and base design elements, power supplies, regenerative life support systems and agricultural technology.

A baseline mission plan for establishing an initial Mars base with a crew of 15 is described. Three redundant interplanetary spacecraft depart from an assembly point at the Space Station. After entering a trans-Mars trajectory, the spacecraft are linked together and spun for artificial gravity. The interplanetary assembly uses a Mars powered flyby trajectory and returns to Earth. Biconic aeroshell shuttle vehicles depart the interplanetary vehicle a few days before Mars encounter and aerocapture to the Mars surface. The shuttles refuel on Mars using a CO-O_2 propellant combination produced from Mars atmospheric CO_2. Missions are timed so that the base is permanently occupied. The crew stays on Mars for two years and is relieved at the next interplanetary flyby opportunity. After the relief crew lands, the first crew departs Mars on the shuttles for rendezvous with the interplanetary vehicle on the return leg to Earth. Immediately prior to Earth encounter, the returning crew boards the shuttle vehicles which aerocapture to the space station in LEO.

While establishing a manned base on Mars is more logistically difficult than a Lunar base, utilizing Martian resources will allow a rapid development of self sufficiency. The Mars atmosphere will provide an easily accessible source of volatiles and can be processed to obtain breathable air and water in addition to rocket propellant. Mars regolith will provide soil for greenhouses after washing to remove salts. With the experience gained from a Lunar base, most necessary consumables can be provided on Mars beginning with the first mission.

MARS: THE NEXT MAJOR GOAL? Elbert A. King, Department of Geosciences, University of Houston, Houston, Texas, 77004.

Virtually everyone believes that we will send manned missions to Mars and that it is desirable to do so. However, in most mission sequences Mars appears far in the future. This need not be the case. Why go to Mars? Put very simply, it is the most "human user friendly" planet in the Solar System next to Earth. The volatiles-rich atmosphere and surface offer the potential for aerobraking as well as the production of water, oxygen, rocket propellant and numerous other resources. It is a full scale planet with more terrestrial-like geological processes than the Moon or other small bodies. The substantial gravity field provides a familiar environment in which to work. There is intense scientific interest in the possibility of present or past life on Mars. Also, some Martian rocks may be very similar to terrestrial lithologies, if the SNC meteorites are indeed of Martian origin. Mars has two small moons that offer important mission options and staging sites, including possible production of water and other volatiles. Not least important is the public awareness and interest in Mars! Even with all its attractive features, Mars is an extremely harsh environment, but compared with the Moon it is a paradise!

Energetically, there is little difference between missions to the Moon and to Mars. However, trip time is substantially longer to Mars than to the Moon, approximately 9 months to Mars one way as compared to 3 days to the Moon. Once we have a low Earth orbit space station with the ability for on-orbit assembly of stages and modules, the infrastructure required to support a manned Mars mission is complete. The mission is possible with state of the art hydrogen/oxygen propulsion, but would be greatly enhanced with a higher specific impulse propulsion system.

In order for a manned Mars mission to occur we will need to accept the risks of long duration space missions, develop long term life support technology and develop a greater level of sophistication in mission planning. These will be needed for any ambitious space project. Most of all, we will need a bold political decision! The time is coming very near when an informed decision might be made, provided that we thoroughly examine various Mars mission plans and continue a vigorous program of Mars research and resource evaluation. It should be remembered that we know a great deal about Mars, perhaps more than we knew about the Moon when the Project Apollo decision was made.

It is vitally important that the Mars option not be foreclosed by a premature commitment to a large scale lunar program that would swallow up too much of the anticipated NASA budget. Such a commitment probably would result in a delay by decades of the first free world manned mission to Mars!

DESTINATIONS BEYOND THE SPACE STATION: A COMPARATIVE ASSESSMENT,
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This paper reviews studies performed on the accessibility of and materials likely to be found on near-Earth objects: the Moon, Mars, Phobos, Deimos and selected Earth-approaching asteroids. Values of velocity increments (Δv) and travel times for round trip manned missions to these objects are given for opportunities near the turn of the century. I also present a comparative assessment of near-term materials utilization and bootstrapping, e.g., refuelling, life support, radiation shielding, and space structures assembly.

The Moon is more accessible in travel time (days rather than months or years) while Phobos, Deimos and selected near-Earth asteroids are more accessible in Δv. The latter objects are more likely to contain water resources, providing for more rapid growth of self-sufficiency in space. Phobos and Deimos have the additional advantage of being bases for the exploration of Mars.

My analysis concludes with a recommendation of an overall program of exploration and materials utilization leading to large-scale space industrialization and settlement.

THE MOONS OF MARS: A SOURCE OF WATER FOR LUNAR BASES AND LEO, Bruce M. Cordell, General Dynamics/Convair, San Diego

While oxygen is plentiful on the lunar surface, water and hydrogen are very scarce. Hydrogen is essential to life support and industry on a lunar base and oxygen will be required by space stations and vehicles in Earth orbit. The obvious source for these substances is Earth, although severe delta-V penalties are inevitable in this approach. Earth-approaching asteroids and Phobos and Deimos (PhD) have also been suggested.

Phobos and Deimos appear to be low density, carbonaceous, volatile-rich moons. Up to 20% of these bodies may be loosely bound water; the total PhD water reservoir may be 10^{18}grams.

In this paper the potential for PhD to contribute volatiles to the Moon and LEO is assessed. A concept for a mission is suggested originating at the lunar base which delivers large quantities of PhD waters to the Moon. A Mars transfer craft is launched at full Moon and aerobrakes at Mars before rendezvous with its satellites. A manned permanent station on PhD processes moon material to extract water. During Earth approach aerobraking places the spacecraft into lunar trajectory. An entry vehicle with tanks can deliver water to LEO by separating from the main Mars craft and utilizing aerobraking.

The advantages of this Moon-PhD loop include: (1) low delta-V's and cost compared to closed Earth-Moon circuits, (2) both LEO and the Moon are supplied with hydrogen and oxygen, (3) environmental risks associated with launches from Earth are reduced, (4) hydrogen and oxygen mined from PhD may be used as Mars craft propellants, and (5) this Moon-PhD loop provides an economic stimulus to further explore the Martian moons <u>and</u> Mars itself.

MAN AND THE PLANETS

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Leon T. Silver, Professor of Geochemistry, California Institute of Technology

The events of the decade of Apollo and Skylab have provided many individuals on the earth with a new sense of direction comparable to that experienced by the free inhabitants of the youthful United States 200 years ago. This sense of direction looks toward the creation of new civilizations by mankind in space. The periods during which major steps can be taken to create those civilizations, of necessity, will occur rarely. Major pulses of such activity will be interspersed with cycles of both crisis and general technological, scientific, psychological, and political development. At any given time, the contributions to the future in space by individuals of vision are two-fold; first, they must keep alive the dreams of human civilization in space and, second, they must see that free men have the basis of understanding and the means for action to support the next steps by mankind in space. However, these contributions can only be made if we succeed in communicating their worth and meaning to the people and their leaders.

This was the essence of the discussions at the Fairchild Conference on the Manned Exploration of the Moon and Planets held August 7 and 8, 1975, at the California Institute of Technology.

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SELENE: UNMANNED, GLOBAL LUNAR EXPLORATION AS THE INITIAL PHASE OF THE LUNAR BASE PROGRAM. Alan B. Binder, NRC Senior Fellow, NASA, Johnson Space Center, Houston, TX 77058.

The 6 manned Apollo and 3 unmanned Luna sample return missions provided us with a wealth of geophysical and geochemical data about the moon and lead to a first order understanding of its developmental history. As a result, we have sufficient knowledge to proceed with the development of a lunar base, even if no new exploration missions were flown before such a base was established. However, the surface area of the moon is equal to that of the combined North and South American continents and the 9 Apollo and Luna landing sites were restricted to an area about equal to that of the midwest USA. Thus, even though we could proceed with the founding of a lunar base without a global definition of lunar resources, seismicity, tectonics, etc., it seems prudent not to do so. Given the costs of manned surface exploration on the global scale, it is clear that such a new lunar exploration program would have to be unmanned if it were to be carried out prior to the establishment of the manned base, e.g., in the early 1990's. With these goals and limits in mind, I have propsed a lunar program, Selene, which has as its goals the setting up a global network of 16 ALSEP type geophysical stations (consisting of seismometers, heatflow probes, magentomerters, mass-spectrometers, etc.) and returning to earth 1 kg of rake samples from selected sites (1). Initial engineering studies done at ERNO in Bremen, W. Germany (2) and at JSC in Houston (3) suggest that the global array of geophysical stations could be set up with 3 shuttle/centaur flights and that 9 return sample missions could be carried out with 3 additional shuttle/centaur flights, at a total cost of $2 billion. Conceptually, the Selene system would consist of a basic lander module which could deliver various payloads to the lunar surface, i.e., the geophysical stations and the sample collection/return stage system. Once developed for the proposed program, this landing system could be used for additional Selene sample return and/or geophysical station missions as scientific needs arise during the development of the lunar base. Further, the Selene lander could be used to land rovers, which have been suggested for traverse science experiments and for lunar base site certification missions, as well as land pilot plants to test various lunar material processing proceedures.

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THE LUNAR BASE: A RE-EVALUATION OF ITS IMPORTANCE AS A MAJOR U.S. SPACE ACTIVITY

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This paper re-evaluates a scientific base on the Moon as a major 21st century space activity for the U.S. Post-1972 developments influencing such a re-evaluation include: (1) Resumption of planetary exploration by the U.S., (2) Proposal of a permanent Space Station as a national goal, (3) Establishment of an operational Space Transportation System, (4) Assimilation of scientific results of the Apollo lunar missions, (5) Technical progress in fields such as artificial intelligence, robotics, remote sensing, communications, and materials science, (6) Reorientation of earth sciences toward continental structure and early evolution, and (7) Continued high level of Soviet space operations, with anticipated development of new launch vehicles.

Early objectives for a lunar base have already been achieved to some extent by the Apollo Program and various satellites in low earth orbit. However, the Apollo results also showed the essential feasibility of a lunar base with regard to surface environment, trafficability, and landing sites. Consideration of these and the developments previously listed indicates that, on balance, the lunar base remains an extremely attractive focus for next-century American space activities. In addition, the following factors support the need for a lunar base. (1) Many first-order scientific questions about the Moon remain unanswered. (2) The success of astronomy from low earth orbit has revealed many more celestial objects than can be studied adequately by existing and planned instruments, in particular the Space Telescope. (3) A lunar base program would, like the Apollo Program, provide great stimulation to space technology because lunar missions are essentially <u>short interplanetary missions</u>, and lunar capabilities can in principle be up-graded for interplanetary missions. (4) The potential feasibility of using magnetically-launched lunar materials (Al, Fe, Ti, Mg, O, and Si) for large structures in near-Earth space has now been demonstrated.

In summary, the lunar base is still a major contender for the focus of U.S. space efforts in the next century. It is urged that initial steps for a return to the Moon, specifically the Lunar Geoscience Orbiter, recommended by the Solar System Exploration Committee be given a high priority in future plans. In addition, Space Station modules should be designed for eventual adaptation to use on the lunar surface, as proposed by NASA-funded studies in 1971.

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MERITS OF A LUNAR POLAR BASE LOCATION

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Because the Moon's spin axis is inclined only 1 1/2 degrees off normal to the plane of the ecliptic, there are no seasons on the Moon. As a result, near the poles there are regions in permanent shadow and possibly regions where the Sun never fully sets. The permanent-shadow regions theoretically should be very cold: temperatures there may be as low as 40 K. Such cold environments, with continuous sunlight nearby, are inviting sites for thermodynamic systems. A lunar base will in any case be largely underground for radiation shielding. If located near a pole, it need not be designed to survive the two-week lunar night, because solar electric power and piped-in solar illumination are continuously available. (The design does, however, have to handle occasional lunar eclipses.) Access from lunar orbit is good because a polar orbiter would pass overhead about every two hours. Habitat and farm conditions are easily kept constant. Waste heat rejection should be much easier than in the widely-varying thermal environment of lower latitudes. Polar cold-trapped volatiles may be available, and if so will dominate the choice of base site. But even if no useful volatiles are naturally present, the cold regions provide convenient storage sites for volatile products of material processing in the base - important when transport logistics are considered. Also, the polar sites offer excellent astronomical opportunities: Half of the sky is continuously visible from each pole, and cryogenic instruments can readily be operated there. A geochemical and topographic survey from polar orbit is the next logical step in determining the real merits of a polar base site on the Moon.

LUNAR SCIENCE FROM A MOON BASE: ANSWERING BASIC QUESTIONS ABOUT PLANETARY SCIENCE. G. Jeffrey Taylor, Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131

In a sense, the Moon is the cornerstone of planetary science. This most accessible of planetary bodies other than Earth contains a treasure of information about the origin and early evolution of the terrestrial planets and the larger satellites of the outer planets. The Moon was geologically active enough to demonstrate many of the processes that occurred soon after planets formed, but this activity was not so vigorous as to erase all record of how it formed. Consequently, the Moon contains information about its origin (cryptically inscribed, but undoubtedly recorded); its early differentiation into core(?), mantle, and crust (written much more clearly, though still undeciphered), its subsequent chemical evolution (clearer), and its impact history (dramatically written on its cratered face, but not yet translated in detail). If we can understand these processes on the Moon, we will be much closer to understanding them on other bodies, including Earth.

We have learned much about the Moon from study of Apollo and Luna samples, and progress continues to be made because these complex materials have not been examined in sufficient detail, even after fifteen years of effort. Nevertheless, many problems remain unsolved. We do not yet know how the Moon formed (though the problem is more constrained since Apollo). Nor do we understand in detail how it evolved. To fill these fundamental gaps in our knowledge of the Moon, we must answer numerous questions: What is the nature of the lunar interior? Is there a core? If so, what is it made of, how large is it, and when did it form? How much does the crust vary in thickness? Does it vary in composition laterally and vertically? How old are the oldest rocks? Can we sample them? What are the ages of the youngest rocks? Over what period of time did the large basins form? What were the effects of their excavation on subsequent igneous activity? Are observed compositional differences on the lunar surface due to immense impacts hurling materials across it, or do they reflect lateral gradients in chemistry? From what depths do giant impacts dredge up rock? What is the Moon's bulk composition? Continued work on lunar samples will provide additional clues, but the answers must come ultimately from a return to the Moon for detailed studies.

Here is a partial list of the kinds of studies that could be done: The first step ought to be global photographic, geochemical, and geophysical mapping of the moon by a Lunar Polar Orbiter. A seismic network of at least 30 stations would reveal the nature of the lunar interior. Rocks from the lower crust and ancient intrusions are probably present in the central uplifts and walls of large lunar craters, such as Copernicus and Tycho on the nearside and King on the farside; sampling these would help understand early lunar igneous activity and perhaps whether the magmas that formed mare basalt flows reacted with rocks in the lower crust as they oozed toward the surface. Traverses across the younger basins, such as Orientale, would shed light on the processes that operate during huge impacts and reveal how effective such impacts are at transporting materials across planetary surfaces. Samples of individual flows of basalt, obtained by drilling hundreds of meters or scaling cliffs in rilles, would establish the compositional variation at a given location. Ancient regolith layers between basalt flows may contain a record of the sun's activity as long as 3.8 billion years ago.

Most lunar scientists believe that the outer few hundred km of the Moon was molten, or at least substantially so, when it formed. If this happened on Earth it would have important implications about the formation of the crust and mantle. Similarly, the intense bombardment the Moon suffered until about 3.8 billion years ago might have affected greatly the evolution of continents on Earth. Thus, answering questions about the Moon answers questions about Earth and the other planets as well.

ASTRONOMICAL OBSERVATORIES ON THE MOON

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Over the next decade, NASA, ESA, and the national space programs of several other nations plan to develop and deploy in near earth orbit a series of quasi-permanent astronomical space observatories, which will allow nearly complete coverage of the electromagnetic spectrum, ranging from the submillimeter band to high energy gamma rays. These new observatories will provide unprecedented sensitivity and resolution, amounting in many cases to improvements of 2 orders of magnitude or more compared to present instruments, for the study of fundamental questions relevant to enigmatic phenomena occuring on virtually every scale in the universe, ranging from the formation of planetary systems and the evolution of individual planetary atmospheres, surfaces and interiors to the formation and evolution of galaxies, quasars, and clusters of galaxies. We can anticipate that this new generation of instruments, in the process of providing a resolution to the fundamental questions posed by those astronomical phenomena which are enigmas today, will uncover new phenomena both anticipated and unanticipated, and will pose new and more fundamental questions concerning phenomena which were thought to be well understood. We can, therefore, even before the operation of this new generation of space observatories, foresee the need for astronomical instruments whose sensitivity and resolving power must exceed those of present instruments by 4 to 6 orders of magnitude. In order to achieve performance of this magnitude, telescopes of very large aperture, and sophisticated interferometric arrays will be required.

The surface of the moon offers several unique advantages as a site for advanced astronomical instrumentation; these include shielding from terrestrial emissions, both natural and manmade, shielding from the earth's geocorona and radiation belts, a very long sidereal period for astronomical objects (potentially important for precise Doppler measurements), and a stable low-gravity high-vacuum platform for precise interferometric and astrometric observations. The moon may also provide the best location for the study of neutrinos and gravitiational radiation from astronomical sources.

It is important to begin detailed engineering studies of the relative merits of the lunar surface and near earth orbit for the development of very advanced astronomical instruments designed to achieve ultra high (microarcsecond) astrometric positional accuracy and angular resolution with interferometric arrays, and large aperture telescopes designed to achieve greatly enhanced sensitivity for the detection and spectroscopic study of very faint sources such as primordial galaxies and planetary systems orbiting other stars in our galaxy.

IRRADIATION OF THE MOON BY GALACTIC COSMIC RAYS AND OTHER ENERGETIC PARTICLES*

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Men and sensitive instruments on a lunar base can be profoundly affected by the radiation environment of the moon. This paper outlines the nature of the ionizing radiation incident upon the lunar surface. This radiation comprises the galactic cosmic rays (GCR) and energetic particles accelerated in the solar neighborhood. The latter consist mainly of solar energetic particles (SEP) from flares, and of other particles energized in the heliosphere. In another paper presented at this symposium, R. Silberberg et al. deal with the effects of cosmic-ray secondaries generated in lunar materials, and the resulting radiation doses. The cosmic radiation bombarding the moon is similar to that incident upon the earth's magnetosphere. It consists overwhelmingly of relativistic and near-relativistic atomic nuclei ranging in energy from $\sim 10^8$ to 10^{20} eV. Approximately 98.6 per cent of the nuclear particles, whose composition extends from the lightest elements to the actinides, consist of hydrogen and helium. The remaining ~ 1.4 per cent span the rest of the periodic table, with conspicuous peaks in abundance at C, O, Ne, Mg, Si, and Fe. The GCR composition is roughly similar to that of the sun, with some notable differences. In addition, there is a component of relativistic electrons comprising ~ 1 per cent of the incident GCR flux. Differential energy spectra are presented for these various components. The intensities, composition , and spectra of the SEP and of the particles accelerated in the interplanetary medium are then reviewed. We also summarize the analytic models developed by the NRL group to describe the energy spectra and elemental compositions of the various components. The purpose of these models is to provide a convenient tool for calculating radiation effects. In addition, remaining gaps in the extensive data base extant on this subject are filled provisionally by these models.

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NEUTRINO MEASUREMENTS ON THE MOON, A. G. Petschek, Los Alamos National Laboratory, Los Alamos, NM 87545 and New Mexico Tech, Socorro, NM 87801.

Large detectors such as the Kolar Gold Fields Nucleon Decay Experiment (1), the Irvine-Michigan-Brookhaven detector (2) and the Kamioka Nuclear Decay Experiment (3) have appreciable rates of neutrino interaction. Gaisser and Stanev (4) compute 100 to 200 neutrino interactions per kiloton - year of exposure. The masses are 0.14 ktons for KGF, 3.3 ktons for IMB and 3 ktons for Kamioka. It has been suggested (5) that a proton decay lifetime of 10^{34} or 10^{35} years could be measured on the moon. This corresponds to 0.06 or 0.006 decays per kton-year if all the nucleons are active so that exposures of 100 to 1000 kton-years will be required. The solid angle subtended by the earth at the moon is $1/2 \cdot 10^{-4}$ of 4π so that the counting rate for neutrinos originating in the earth's atmosphere should be $\sim 10^{-2}$ per kton-year or a few (1-10) counts during the exposure of a lunar nucleon decay experiment. Very few neutrinos originate from cosmic rays on the moon because of the higher density. The background competing with earth atmosphere neutrinos is due to astrophysical neutrinos (6) which at low energies (1 GeV) and on earth are ~1% of atmospheric neutrinos on earth. At energies above 1000 GeV, astrophysical neutrinos exceed atmospheric ones even on earth.

A large nucleon decay detector on the moon would allow neutrino astrophysics to be undertaken at energies below 1000 GeV, where the atmospheric background makes earthbound measurements impossible. Such a detector would also see a few counts from earth atmosphere generated neutrinos and might shed some light on neutrino oscillations. The parameter of interest here is (flight distance)/(neutrino energy) which is substantially larger at 1 GeV and earth-moon distances than at 1 MeV and typical reactor-detector distances or hundreds of MeV and accelerator target-detector distances.

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GEOTECHNICAL IMPLICATIONS FOR A LUNAR BASE,

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Considerable geotechnical information has already been obtained from the Surveyor and Apollo missions. It is known that the top 10 to 20 cm of soil can be fairly loose, especially on the rims of small (1-2 m), fresh craters, where Astronaut bootprints were observed to be greater than 10 cm deep. On the average, the bootprints were approximately 1 cm deep, which is still indicative of a relatively loose soil. However, below this surface layer, the density increases rapidly to nearly the maximum achievable in the laboratory by vibrating the soil. Much higher, in fact, than can be accounted for by simple self-weight compression of the soil in lunar gravity. Hence, the lunar soil is interpreted to consist of a loose surface layer, approximately 10-20 cm thick, which has been stirred up by the "gardening" process of micrometeorite impacts. These same impacts, in turn, have densified the underlying soil by vibration to essentially the maximum density. This is in stark contrast to some early models of the moon which imagined the soil to be so loose that the lunar module and the Astronauts would sink out of sight. For most engineering calculations, such as mass requirements for radiation shielding, the lunar soil may be assumed to have a density of 1.5 to 1.8 g/cm^3.

The shear strength of the lunar soil is more than adequate to support any of the structures that have been suggested for a moon base, with two possible exceptions that will be discussed below. Hence, excavating to bedrock (if it can be found) or driving piles is not necessary. In fact, the shear strength and compressibility of the lunar soil is sufficiently well known that foundation supports can be designed for nearly all structures, as well as vehicles.

One of the exceptions that may present special foundation problems would be a structure that is especially sensitive to differential settlements, such as an observatory. Another would be rotating machinery, such as a pump or a ball mill, which would have to be designed such that the operating frequency is sufficiently different from the resonant frequency.

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STRUCTURAL PROPERTIES OF LUNAR ROCK MATERIALS UNDER ANHYDROUS, HARD VACUUM CONDITIONS

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Construction of lunar-based facilities must take maximum advantage of indigenous rock materials. For example, tunnels and lightweight surface shelters covered with lunar soil can provide radiation and thermal moderation at potentially large savings in earth-lift requirement. The structural properties of lunar materials are substantially different than analogous materials on Earth because of the absence of hydrolytic weakening effects in a hard vacuum. Rock fracture strength is increased by at least a factor of two in a moderate vacuum compared to normal laboratory humidity conditions.[1] Lunar soil cohesion and angle of repose are also enhanced under vacuum conditions.[2] These anhydrous strengthening effects and low lunar gravity may make possible lightly supported rock structures not possible on Earth. For example, an airtight fabric mesh (tent) covered with lunar soil may be an adequate shelter for lunar base personnel. Similarly, tunnel structural supports for extraction of lunar ores may be reduced or unnecessary compared to Earth conditions. Finally, the tensile strength of lunar-fabricated structural components such as glass fibers should be much greater than on Earth because of the absence of water stress corrosion mechanisms.

Exploitation of the enhanced, anhydrous structural properties of lunar materials will require more detailed knowledge of these properties than is currently available. The best way to measure these properties is with a lunar-based rock mechanics laboratory in which lunar rock and soil samples are prepared and tested under *in situ*, hard vacuum conditions. A simple, electrically actuated screw press operated as an inside-out glove box would seem appropriate. The lunar-based structural properties laboratory should be an early, high priority facility to enable timely use of the structural data for the major construction phase of the base.

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IN-SITU ROCK MELTING APPLIED TO LUNAR BASE CONSTRUCTION AND FOR EXPLORATION DRILLING AND CORING ON THE MOON*

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The Los Alamos National Laboratory research and development project in excavation technology conducted from 1962 to 1976 (1, 2, 3) has demonstrated the potential technical advantages of a rock and soil melting process for lunar excavation applications (4). Field and laboratory demonstrations of prototype rock and soil melting systems under terrestial conditions have illustrated the unique features of this technology that have application to lunar base facilities construction and exploration drilling and coring on the moon. These features are: the melting system is relatively insensitive to rock or soil type, the technique can be automated for remote and untended operation, the melting penetrators create a formed in-place rock-glass structural lining (casing), selective formation of debris (or "cuttings") in wool or glass pellet forms is possible, and electrical energy is used as power for the melting penetrators. These results were obtained with soil and rock samples at terrestrial ambient conditions of moisture content and partial pressures of oxygen. It is anticipated that vacuum conditions and essentially zero moisture content of the lunar soils should significantly reduce thermal diffusity. Therefore reduced heat losses could be expected during lunar use. The absence of moisture and oxygen should reduce the corrosion rate of the tungsten and molybdenum penetrators. The most important parameter in the rock and soil penetration process is melt viscosity. This property for lunar soils and basalts, as reported in the literature (5), appears to be within the same range as terrestial material of roughly the same composition. In any event tests and experiments at vacuum condition could be performed in order to extend the designs perfected in the past Los Alamos work to lunar soils and rocks.

Several primary structural applications of soil melting penetrators to construction of lunar base facilities are reported in (4). A variety of drilling and coring penetrator configurations are possible (6) with the rock and soil melting. It is noted that all borehole construction processes will produce glass lined, stabilized holes. The rock glass obtained in terrestial experiments has structural properties equal or superior to portland cement (7). Such penetrator designs could be adapted to a variety of exploration and drilling tasks on the moon.

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USE OF LUNAR MATERIALS IN THE CONSTRUCTION AND OPERATION OF A LUNAR BASE. Wolfgang H. Steurer, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

The paper discusses the advantages which can be derived from the use of lunar materials in the establishment and operation of a Lunar Base. Useful materials which can be obtained from the Moon's own resources are defined by a three-step analysis: (1) Evaluation of lunar raw materials with regard to potential products; (2) Definition of the envisioned facility and operational requirements of a lunar base in terms of materials and consumables; (3) Identification of those requirements which can be satisfied from lunar resources. It is apparent that the most useful and most readily attainable lunar products are silicate shapes ("bricks") for construction, and oxygen for life support and propulsion.

Production methods are evaluated with regard to process efficiency (output as fraction of throughput) and with regard to facilities mass, energy and operational requirements. Overall production effectiveness ("pay-back") is determined by a trade-off of the imported facility mass vs. total product output over the facility life cycle and process efficiency. Process efficiency data obtained in laboratory experiments indicate that for the production of oxygen a pay-back ratio of 50 is readily achievable.

The effect of the use of lunar materials upon the growth and cost of a lunar base is examined. It is argued that it is desirable to provide a starting supply of oxygen and construction materials for the first crew arrival by means of unmanned precursor missions using automated/teleoperated production facilities and existing flight hardware. It is shown that using the shuttle-launched Centaur G' as delivery system, a net payload of 1.8 tons can be placed on the Moon, capable of producing 10 tons of oxygen or 3000 ft^3 of "bricks" per year. The feasibility and usefulness of such precursor missions is evaluated.

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CONCRETE STRUCTURES FOR LUNAR BASE CONSTRUCTION, T. D. Lin, Construction Technology Laboratories, Portland Cement Association, Skokie, Ill. 60077.

Developing lunar bases, according to the National Aeronautics and Space Administration's plan, will be one of the priority space activities in the 21st Century.(1) Prior to the establishment of lunar scientific and industrial projects, suitably shielded structures to house facilities and personnel must be built on the moon.

This presentation will discuss a concept of self-growth lunar bases, focusing on structures using concrete made mostly with lunar materials, the only required terrestrial item will be hydrogen for water production.

The use of concrete for space station and lunar base construction was first introduced in the Third California Space Investigators Conference,(2) May 1984. The feasibility of producing concrete made with lunar materials was subsequently discussed in the Summer Workshop jointly sponsored by NASA and California Space Institute.(3)

The objectives of this presentation are: (1) acquaint scientists and engineers in the aerospace field with concrete construction technology, (2) examine NASA published data(4) on lunar soils and rocks for use as aggregate and possible raw materials for producing cement and water, and (3) investigate the technical and economic feasibilities of concrete lunar base construction.

The discussion will cover concepts to produce cement and concrete on the moon, and thermal and mechanical properties of concrete in the temperature range of −250°F to 1600°F.(5,6) Hypothetical examples will be discussed. Stress distributions in concrete structures subjected to 1/6 g, lunar temperature variations, and internal pressures will be presented. These data will be used to develop preliminary designs for concrete structures suitable for the lunar environment.

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CEMENT MANUFACTURE ON THE MOON USING PLASMA TECHNOLOGY:
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Although the initial establishment of a lunar base will rely on terrestrial materials, moon based industries for converting lunar minerals into basic materials of construction will play a vital role in further expansion. Due to the absence of conventional fossil fuels, novel technology relying principally on electric power is likely to be required and plasma technology is an attractive candidate.

Two basic requirements for the application of plasmas to process technology are a plasma generating device and a furnace or reactor system. Plasma generators are either simple graphite electrodes as in conventional electric arc furnaces or plasma torches with water-cooled metallic electrodes. The plasma generated by such devices is at atmospheric pressure with temperatures in the range 5,000-25,000 K. There are three fundamental methods of coupling the energy contained within the plasma to materials:

Plasma Gas Heating, in which a plasma torch is used to heat a process gas to temperatures above those attainable by conventional fossil fuel combustion. The high temperature gas is then used to convey the required reaction enthalpy to the reactants.

Molten Pool Transferred Arc Furnaces, in which metal/slag reactions take place in the molten pool with the major energy input provided via the anode attachment zone on the molten surface.

In-Flight Plasma Reactors, in which solids are introduced directly into the plasma medium and undergo reactions while in flight. Basic geometries are shown in Figure 1.

Of particular importance to a lunar base program is the potential application of such systems for the production of metals and alloys from metallic oxide ores and the production of cementitious materials from anorthositic minerals. Current research at MRRC includes both the study and development of plasma systems and research on particular applications. For the production of metals the reduction of iron oxides, chromites and ilmenites is being studied. In the cement field a new program has been recently established to explore the manufacture of novel cements using plasma technology. Expansion of this program using feed materials simulating lunar minerals could provide vital information on the feasibility of manufacturing materials of construction on the moon.

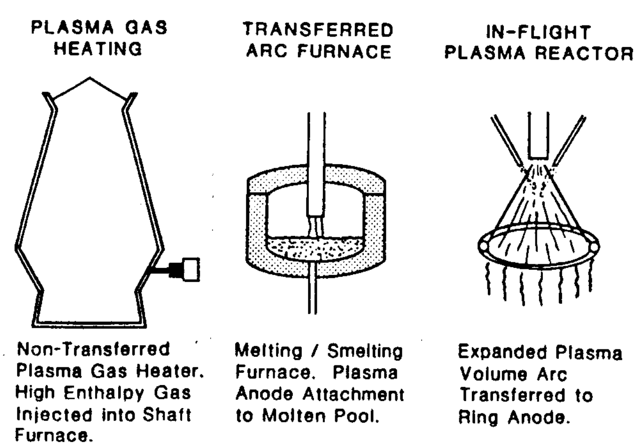

Fig. 1. Schematic of Three Fundamental Types of Plasma Application.

LUNAR CEMENT FORMULATIONS. William N. Agosto, Lockheed Engineering and Management Services Co., Houston, TX 77258

Except for water, the major oxide constituents of common cements, CaO, SiO_2, Al_2O_3, FeO and MgO are abundant in lunar anorthosites and basalts. Concrete made from lunar formulations and aggregates may have many advantages as a building material for space and lunar structures. Its high mass and compressional and flexural strength when reinforced may make it a superior shield against radiation and meteorite impacts. Concrete is fireproof, modular, and suitable reinforcement materials like iron and fiberglass as well as oxygen for the water component of cement can be lunar derived.

The CaO content of lunar anorthosites (<20 wt.%) is below cement formulations (30-65 wt.%). But it may be possible to enrich the CaO content of lunar anorthite to cement levels by pyrolizing it in a vacuum solar furnace with lunar derived phosphate (whitlockite) according to a reaction like:

$$Ca_3(PO_4)_2 + CaO\ Al_2O_3\ 2SiO_2 = 4CaO\ Al_2O_3\ 2SiO_2 + 2P + 2.5O_2 \quad (1)$$

phosphate + anorthite = slag(melt) + (vapor)

King (1982) has shown that vacuum pyrolysis of basalts in a solar furnace at approximately $3000^{\circ}C$ vaporizes the more volatile oxides. Accordingly, it is likely that P_2O_5 in the phosphate of reaction (1) will vaporize and, to some extent, dissociate under those conditions increasing the CaO content of the slag residue. Maximum enrichment in reaction (1) increases CaO from 20 wt.% in anorthite to cementitious levels of 50 wt.% in the slag.

Phosphate consumed in reaction (1) can be regenerated by reacting the phosphorus product with lunar augite pyroxene at elevated temperatures in a reaction like:

$$11(Ca_{.273}Mg_{.273}Fe_{.454})SiO_3 + 2P = Ca_3(PO_4)_2 + 5Fe + 8SiO_2 + 3MgSiO_3 \quad (2)$$

augite + phosphorus = phosphate + iron + silica + enstatite

Agosto et al. (1980) have proposed reaction (2) as a phosphate generating process in the mesosiderite meteorites where phosphorus derives from meteoritic metal. Meteoritic metal also occurs in lunar soil and can be beneficiated as a source of iron, nickel, phosphorus and sulfur (Agosto, 1981). In addition, phosphate occurs as a minor component of KREEP soils and basalts up to 1 volume %. Alternatively, terrestrial phosphates could be imported to space and phosphorus recycling losses of the CaO enrichment process replenished from lunar phosphate.

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MAGMA AND CERAMIC STRUCTURES GENERATED IN-SITU

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Lunar base structures can be generated and cast, based on the principles of the natural space formation created by magma-lava flow. By utilizing existing lunar contours or by forming mounds of lunar soil to desired interior spaces, structures can be cast in-situ with the generated magma. Either way the upper layers of the mounds at the apex must consist of the glass-ceramic (1) lunar resources to generate the magma flow with the focused sunlight (2). As the flux contained, low-temperature molten composite flowing with the low gravity crawl the lava crust can be formed in the spiral, circular or vertical rib troughs on the mound. A controlled flowing magma can cast, single or double-curvature, monolithic shell structures.The underlying loose soil mound can then be excavated and packed over the monolithic shell for radiation/thermal/impact shielding (3). The sculpted spaces with its natural colors or semi-glazed finishes give the added human dimension. Similar structural and finishing techniques can be used in parts of the infrastructure elements such as ducts, pipes and pavings. Research is needed to determine the magma crust formation patterns and the span limitations. The natural lava structures of the Craters of the Moon National Monuments can provide a case study in the design development stages.

Constructing lunar base structures utilizing "lunar adobe" blocks or rammed soil through the use of the glass-ceramic, low-temperature composites which are fused by the focused sunlight can be done by employing the earth-structure systems (4) and heat fused spot-mortar. The noncurved conventional structural members can also be fused-cast in a prefabricated system.

Ceramic structures of limited spans can be cast in-situ in space. A centrifugally gyrating space platform, moving in three dimensions, is but a potter's wheel in space where a mass of known lunar minerals can be "thrown" and a space-pot formed. A mass of glass-ceramic lunar substance centered on the rotating platform with focused sunlight heat and tensile fiber can result in a monolithic stoneware or ceramic structure. A souble-shell pot with locked air and/or packed insulation can provide the radiation/thermal shielding. A similar rotating wheel can form short span curved ceramic or "earthenware" structures suitable for lunar base, and at the same time be utilized for infrastructure parts. The shielding ceramic tiles of the Space Shuttle points to the potential of the material for the lunar and space applications.

Accumulated human skills of Earth-Architecture systems, especially those of arid lands with soil and rock as the only resources, make it possible to form limited structures on the moon utilizing lunar rocks, dry-pack, corbeling and leaning arch techniques. Such structures, along with the curved forms, can create a permanent sun-shade zone and thermobalancing environment. American Indians, Middle Eastern and European earth and rock structures remaining through centuries point the way.

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Utilization of Lunar Chemical Elements to Manufacture Near-Net Shape Ceramics and Alloys by Condensed-Phase Combustion

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Combustion synthesis, also known as self-propagating high-temperature synthesis, can be used to produce advanced materials, including alloys and near-net shape ceramics by means of highly exothermic solid-state chemical reactions. The feasibility of using this technique as a materials processing technology on the lunar surface will be discussed. Examples of exothermic chemical reactions which may be used to manufacture ceramic or alloy components will be presented.

Relative simplicity, the ability to use abundant lunar materials, and possible process enhancement under low gravity conditions, make combustion synthesis a potentailly attractive method for large-scale production of various materials on the Moon. Since the heat necessary for chemical reaction is supplied by the exothermic heat of reaction, equipment such as high-temperature furnaces normally needed for ceramic processing are not required. Heat necessary to ignite the exothermic reactions could be supplied by a solar furnace. Large-scale synthesis of complex ceramic or refractory alloy bodies can be carried out rapidly in the high-vacuum on the lunar surface.

Combustion synthesis techniques may be used to produce refractory materials from chemical elements commonly found on the lunar surface such as aluminum, iron, titanium, zirconium, and silicon, or from their corresponding oxides. Since adiabatic combustion temperatures for many solid-state combustion reactions exceed the melting temperatures of the ceramic or alloy products, the resulting ceramic or alloy may possibly be cast into high-density, complex shapes. Such materials could potentially be used to produce heat shields, pipes and tanks, bricks, or other structural components suitable for use in the lunar environment. Oxide ceramic heat shields for vehicles employed in lunar supply of oxygen to low-Earth orbit facilities may also conceivably be fabricated.

Because combustion synthesis frequently involves either a completely molten or partially molten phase, gravity-induced convection strongly affects the mixing of reactants and products. Mixing in turn influences reaction rates, ignition, combustion wave structure, and the distribution of products in a multi-component exothermic reaction system. The reduced gravity of the lunar environment could conceivably influence the chemistry associated with combustion synthesis processes, resulting in potentially higher quality products than those obtained on Earth.

RADIO INTERFEROMETRY ON THE MOON, Jack O. Burns, Dept. of Physics and Astronomy, Univ. of New Mexico, Albuquerque, NM 87131

The technique of aperture synthesis radio interferometry has proven enormously successful for radio astronomy. Premier instruments include the Very Large Array (VLA) in New Mexico and the proposed Very Long Baseline Array (VLBA) with intracontinental baselines. However, further advances in radio interferometry are fundamentally limited by the atmosphere and the increasing background of terrestrial radio noise. An array of antennas located on the far side of the Moon offers several advantages over a terrestrial or near Earth-orbit interferometer. These include increased sensitivity and resolution of distant sources, superior phase coherence, a radio quiet environment, and thermal stability (with such stability, one could construct fairly simple dishes made of aluminum mined on the Moon). Furthermore, telescopes on or near the Moon could be linked to a VLBA on Earth to produce an interferometer of unprecidented resolving power.

The initial installation may consist of a single dish operating at centimeter or millimeter wavelengths and a simple array of dipole antennas operating at meter wavelengths. The dish antenna could be used for radio communications, as a radio telescope for spectral line studies of molecules, and as one element of a Moon-Earth radio interferometer (MERI). At 20-cm, MERI would have a resolution of 50 microarcseconds, which could theoretically allow us to resolve a Jupiter-like planet orbiting any of the 100 closest stars (out to 30 ly). MERI could be a powerful tool for astrometry. Microarcsecond position accuracy will enable us to perform fundamental experiments in cosmology. Classical distance determination techniques such as statistical parallax could be applied to extragalactic masers, pulsars, and active galaxy nuclei in clusters to accurately measure the Hubble constant of the expansion of the Universe. In addition, MERI could greatly improve the accuracy of the celestial coordinate system and consequently aid in satellite pointing and navigation. With proper spatial frequency sampling using 100-m dishes at the Lagrange points and on the Moon, one could also map active regions on other stars, resolve regions of star formation, and possibly reveal the nature of the engine at the cores of active galaxies and quasars.

A phased array of dipoles at meter wavelengths on the Moon would open a window of the electromagnetic spectrum virtually unexlored from Earth. Useful limits on the acceleration of cosmic ray particles, magnetic fields in extragalactic sources, and detection of Jupiter-like decimetric emissions in other star systems could be possible.

Abstract for Lunar-Base Meeting - Oct 29-31, 1984

Very Low Frequency Radio Astronomy From the Moon

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Possibilities are examined for a very low frequency radio telescope array to be operated in conjunction with a permanent manned lunar base. Significant resolution and useful sensitivity can probably be achieved by using a moderate number of simple wires on the surface as field sensors, interconnected as a Fourier Transform image-forming device. Limitations on performance due to optically active interplanetary plasma are discussed, as well as those due to the radio-leakage and natural radio-emissions of the earth in the event of an earth-facing location of the base.

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GEOPHYSICAL-ASTROPHYSICAL LUNAR TELESCOPE (GALT)

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GALT was proposed for the Apollo program in Feb 1970 by a group at the Manned Spacecraft Center including R. T. Giuli, Y. Kondo, A. E. Potter, and me. Our goal was twofold: (a) to survey lunar surface minerals by day, and (b) to observe celestial objects in far-ultraviolet light at night. The instrument was of conservative design: a 10-inch f/3 Newtonian telescope with a Vidicon detector of 73-arc-min field for lunar surface filter imagery, and a grating spectrograph of resolution 1000 with EMR photomultiplier detectors covering the region 110 to 800 nm for observing celestial objects. The total weight was 23 kg, dimensions 60x60x50 cm.

These goals are highly suitable for a manned lunar base in the 21st Century. Note that goal (a) will provide scientific data on the history of the surface, and practical data on the location of lunar minerals needed for construction and operation of the base. The thin lunar atmosphere can be monitored hour by hour, day and night.

After its launch in 1986 or 1987, the Hubble Space Telescope (1) will provide ample experience with a more sophisticated GALT design. Pieters (2) and her collaborators (3) have shown how the composition of the upper lunar crust can be determined from its reflectance spectrum. It is proposed to design a 1-m (39-inch) GALT with instruments similar to those on ST, but with a new infrared spectrograph sensitive from 0.5 to 2 μm or more for lunar surface reflectance, replacing the Faint Object Camera. For astrophysics, the new GALT would not compete with ST, but would augment ST observations by its ability (using the lunar horizon as a shield) to observe close to the Sun, where comets, inferior planets, and other objects are unavailable to ST.

Of course, pointing control will be simpler for GALT than for ST; thermal problems and total weight need further study. For survey of the lunar surface minerals, it will be desirable to move GALT by lunar flying machine from one site to another. The first site should be on a hill near the lunar base in order to detect useful mineral deposits nearby. A team of 2 or 3 astronauts will be needed to emplace and orient GALT at each site. Commands and data will be telemetered to and from both the lunar base and Earth. Power will be most convenient from an RTG unit. The lunar base will need receiving and transmitting equipment and a computer to control GALT.

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ULTRA-HIGH RESOLUTION STUDIES OF THE SURROUNDING TERRAIN FROM A LUNAR SURFACE TELESCOPE; Thomas A. Meier, Department of Geosciences, University of Houston, Houston, Texas 77004.

The lack of an atmosphere on the moon opens up unique and exciting opportunities for a lunar surface telescope. Besides the obvious uses for deep space observations, a lunar telescope constructed at a topographically high location could be used to make virtually distortionless observations of the surrounding lunar surface. Resolutions of less than a millimeter should be possible at distances up to several kilometers from the telescope, limited only by the optical system of the telescope itself. Over-the-horizon viewing should also be possible with the use of mirrors mounted on towers several kilometers from the telescope or mirrors in lunar orbit. The scientific possibilities of such a telescopic system are tremendous. Sampling sites and even samples themselves could be chosen before manned excursions are sent out. Using visible, IR, UV, and other instrumentation in conjunction with the telescope, spectral/mineralogical measurements could be made at several-kilometer distances, enabling, for example, individual boulders/blocks to be mapped for interesting clasts or inclusions. Other potential uses include mapping of: (1) crater wall/floor structures (using mirrors on towers); (2) crater/secondary crater distribution patterns; (3) ejecta (boulder) distribution patterns around craters; (4) layering/structures in mountains and hummocks; (5) basalt flow patterns; (6) spectral unit distribution; (7) xenolith/exotics locations (via spectral searches). Final notes of encouragement concerning a lunar telescope: (1) Its cost could be sharply reduced by using a high degree of design inheritance from the Space Telescope; and (2) there will undoubtedly be an extreme backlog of observation-time requests for the Space Telescope after its launch, leading to demands for a second space-based telescope -- a role that would be filled by a lunar surface telescope.

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Contamination Problems for a Lunar Observatory

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Most space astronomy has been done in low Earth orbit; some has been done in geosynchronous orbit. Only a very limited amount of astronomy has been done from the surface of the Moon.

Atomic oxygen and particulate material prove to be a problem for orbits defined by the Space Shuttle altitude. Even at the orbital altitude of the Copernicus Observatory (about 700 km), problems were encountered that were interpreted to be glow discharge when the telescope was pointed near the ram vector. At geosynchronous altitudes, the International Ultraviolet Explorer has completed six years with little loss in sensitivity. Nevertheless, its detectors are sensitive to energetic particles trapped in the Van Allen belts; and its solar panels are steadily deteriorating.

The Moon, with its lack of atmosphere, its stable base, and its monthly rotation period is most attractive for astronomical instruments, especially to large optical arrays with milli- and micro-arcsecond resolution and imaging capability. Dust, the solar wind, cosmic rays, and converted showers are some of the contamination sources to be considered.

Contamination to astronomical instrumentation in low Earth orbit, geosynchronous and lunar environments will be discussed.

A Lunar-Based Astronomical or Astrophysical Observatory (LBAO)

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The problems of designing, building, testing, and packaging - for transport to the Moon - of a manned LBAO are formidable; no less formidable are those of lunar surface re-assembly, operation, and maintenance.

If a launch or transport vehicle of the size, say, of the Saturn-Apollos is contemplated, then the author concludes that "traditional" A.O. concepts and constructions must be abandoned, in favor of new types of (optical and radio) telescope configurations, housings, and operations.

"Traditional" glass mirrors and radio antennas, among other elements, must be replaced by lightweight metal or composite-material reflecting surfaces, "erector-set" housings and frames, expandable metal mesh antennas, etc. Several possible techniques for mirror and antenna fabrication are suggested.

If astronomers are to work, preferably in a "shirt-sleeve" environment, with not only electronic detectors but also photographic film, then special housings and remote control are necessary. The author will show a number of configurations, some extant, of telescopes housed so that an image can be brought into a sealed observer's cabin.

The author will suggest also that one <u>use</u> of an LBAO is for certain observations of the Earth's atmosphere.

DESIGN OF LUNAR BASED FACILITIES: THE CHALLENGE OF A LUNAR OBSERVATORY

by
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This paper examines some of the site selection, site preparation, design and construction alternatives to be investigated before a lunar astronomical observatory becomes a reality. It draws upon previous work by the authors (ref. 1, 5, 8, and 9), and critiques of that work as well as recently published reports (ref. 2-7) suggesting types of observational capabilities most desirable for the lunar surface. The physical and mechanical properties of the lunar regolith (ref. 8-10) are significant in developing the substructures with the required stability to support various components of an observatory on the moon. Simple trade studies can help narrow the range of options for these substructures. Desirable goals are predictable stability (within the range of optics/sensors control capability), ease and automation of placement, and trouble-free service over extended periods. The overall lunar environment as it influences the planning for construction activities related to a lunar observatory is examined. Some considerations are requirements for particulate-free surfaces, heat dissipation, design for thermal stresses, particle impact, and radiation exposure. To meet each requirement individually may be accomplished with relative ease, but simultaneously satisfying all will require innovative designs making use of advanced materials, controls, and expert systems.

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Dreams and Realities: The Future in Space

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In a book explaining how John F. Kennedy decided to commit the United States to initial exploratory voyages to the moon, I wrote "the politics of the moment had become linked with the dreams of centuries and the aspirations of the nation, and the result was the identification of space success as a crucial factor in fostering the American national interest."[1] As we begin serious thinking about a permanent return to the moon, it is worth reflecting on the conditions which might make that vision one to which the American nation, alone or with other peoples of the world, aspires. By understanding how societal commitments to prior large space efforts have been made, perhaps we can gain some insight into the evolving process through which society will decide to undertake major space ventures in the future, and into the relationship of current study and research efforts to that decision process.

A review of the decisions to begin the Apollo, space shuttle, and space station programs makes clear the intimate interactions among technological readiness, political salience, and leadership vision in creating a strong commitment and providing the conditions for a successful program. While these three factors were present when the Apollo and station decisions were made, they were largely missing at the time the shuttle program was initiated. The historical record suggests that, for enterprises of the scope and long duration of major space projects, all of these factors should be present at the outset if there is to be a high probability of success.

It is obviously impossible to forecast whether those in leadership positions a decade or more from now will include an expansive space program as part of their vision for the future. It is almost as speculative to discuss which rationale or rationales might be politically (or commercially) so convincing that society would be willing explicitly to commit the human and financial resources required to return to the Moon; such a commitment almost certainly is more than a decade away. What can be discussed now is how to gain the support required to undertake a research and development program aimed at, among other objectives, exploring the feasibility of and payoffs from a lunar base effort.

One approach to such a program strategy is designing a program which proceeds in incremental steps toward a long-range objective, with each step having near-term benefits not exclusively linked to that objective. It is these "in process" benefits which lead to the political and management support required to keep the program going, while allowing advocates of the long-range objective to guide the program in that direction. This approach does not require top level decision makers to commit themselves to a major goal far in advance and provides multiple decision points along the way.

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A HISTORICAL PERSPECTIVE ON A MOON BASE - THE BRITISH EXPERIENCE

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Undertakings not unlike the establishment of a lunar base have occurred many times in human history. As our species has spread across the face of the planet, individuals, cultures, and institutions have been tested in novel environments and circumstances. Of recent examples from the Age of Exploration, most are characterized by the intense cultural and biologic clashes resulting from the arrival of Europeans in places already inhabited. However, there are two cases from the British experience which have much to teach us about the interaction of individuals and institutions, between goals and means. The voyages of Captain Cook and the settlement of Australia can serve as models of possible approaches to the establishment of a lunar base, or illustrate errors to be avoided.

When in 1768, the Royal Society approached His Majesty's government about making worldwide observations of the transit of Venus, a narrow, purely scientific mission into the Pacific was proposed. They nominated one of their own members as leader of the expedition. The Royal Navy, which was paying the bills, chose instead both a broader purpose and a man with the skills to make a success of the mission. James Cook, although not a commissioned officer, had proved his skill in surveying and in independent command in Canada. In three Pacific voyages spanning a decade he made the requested astronomical observations but, more importantly, gave the world a known Pacific. His success was due both to his own skill and to the choice of broad and flexible instructions on the part of the Admiralty.

One of Cook's discoveries was the fertile east coast of Australia. By 1788, the British government had decided to establish a penal colony at Botany Bay to serve as a dumping ground for urban criminals now refused by an independent America. While some supporters of the concept urged the colony be made self-supporting, the idea of prosperous farmer-convicts or even prosperous former convicts did not square with a perceived need for punishment. London was reluctant to provide the means for achieving self-sufficiency. For example, there was no plow in Australia until 1803. The colony struggled for decades, remaining dependant on handouts from London. However, the introduction of sheep as well as the decisions of countless individuals to put down roots in Australia eventually led to the modern nation. Success of the Australian settlement was due both to sustained, if erratic and sometimes inconsistent, support from London and to individual commitments to the enterprise. Success might have come more quickly and cheaply had goals and means been more consistently chosen.

THE EVOLUTION OF CONCEPTS FOR LUNAR BASES

by

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Zdenek Kopal in "The Moon and Man" (Science Journal, May 1969) reflected that the man's aspiration to reach the Moon has a very long history. Lucian of Samosata, wrote about a trip to the moon using the wings from a vulture and an eagle in 165 AD. However, the first mention of lunar colonies appears to be by an English Bishop, John Wilkins, in 1638. From the visions of Kepler to the imaginations of Swift and Cyrano de Bergerac and Jules Verne, the literature continues almost without interruption. Verne's launch (by means of the projectile fired from a gun) of men to the Moon was from Florida but that seems to be about the only parallel with the Apollo missions of the 1960's and 1970's. Much has been learned since William Gilbert's (1540-1603) first map of the Moon. Man has touched some of features discussed by G. K. Gilbert in his 1892 paper for the National Academy of Science "The Moon's Face: A Study of Its Features."

Lunar bases have taken diverse forms as they have evolved in the minds of men. In 1951 Thompson wrote of "The Lunar Base" in the Journal of the British Interplanetary Society. Conquest of the Moon by von Braun, Ley, and Whipple followed in 1953. Rodney Johnson's Astronautic Acta paper on "Planning and Development of Lunar Bases", which was published in 1966, analyzed roles and functions of lunar bases. Types of bases required and possible locations were reviewed. Parallels with Antarctic exploration were discussed. Evolution was seen to progress from discovery and conquest to exploration and then to exploitation. The magnitude of lunar basing efforts seem to be strongly dependent upon the ability to utilize lunar resources (especially water) in operational programs as well as ability to overcome environmental factors and achieve mobility.

An "Initial Concept of Lunar Exploration Systems for Apollo" was prepared and published by Boeing in 1964. This LESA concept for lunar basing resulted in four proposed base models. The bases of the LESA concept envisioned eight to eighteen Saturn V booster launches per year to achieve 36 to 216 man-months per year of lunar base occupancy. Later, in 1967, a Study of Mission Modes and System Analysis for Lunar Exploration (MIMOSA) was completed by the Lockheed Missiles and Space Company. It recommended a plan of lunar exploration and generated three selected lunar exploration programs for possible implementation. Many groups contributed to the LESA, MIMOSA and related lunar base studies. With the close-down of the Saturn V assembly line and the diversion of effort to a resuable booster, the continuity in lunar base planning efforts was broken. As evidence of the change, a NASA-sponsored Space Station Utilization Conference was held at Moffett Field, CA in September 1970 complete with tours of a Space Station Mockup.

Interest in lunar bases was revived as a result of the Satellite Power System Program and Space Colonization studies of the late 70's. The concepts advanced for these programs were based on the potential usage of lunar materials for construction projects in earth orbit.

LUNAR BASES OF THE 21ST CENTURY: ISSUES OF LAW AND POLICY

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The introduction stresses the importance of the exploitation of special resources and the opportunities for such likely to arise in the 21st century.

The discussion moves on to an analysis of applicable international space law, especially the provisions of the Outer Space Treaty and the Moon Agreement. Attention is drawn to the right of visitation and some of its preconditions. Issues and policies are analyzed with respect to the exploitation of lunar resources. Jurisdictional and liability issues are addressed. The question of registration in connection with materials brought from Earth to be used in the lunar base is also discussed.

The concluding remarks will focus on some of the unresolved issues and policies which will have to be clarified nationally and internationally before the establishment of a lunar base in the 21st century.

LEGAL JURISDICTION AND CONTROL OVER LUNAR RESOURCES AND SETTLEMENTS

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ABSTRACT NOT RECEIVED IN TIME FOR INCLUSION

Toward a Lunar Base Program Methodology

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The lunar base program affords an opportunity to examine a detailed methodology required for early decisions on how best to develop the program plan. At present, the twin issues of technical and cost uncertainty dominate the discussions of the lunar base program and decision making. As new knowledge is acquired through research and development it must be applied to the decision making process in a timely and effective manner to fully evaluate potential costs and benefits. One approach to analyzing systems and economic factors involved in the lunar base would be as follows:

The first criterion for any methodology is that it deal effectively with uncertainty. Our current understanding of the nature of a lunar base system precludes defining a specific set of technical or cost parameters. We may construct models using near-term systems about which a great deal is known and reflect more confidence, or utilize advanced concepts which will appear promising - but which contain uncertain parameters. The methodology proposed should analyse risk vs. reward for a variety of concepts and must possess the ability to examine the full range of possible outcomes for alternative systems. Often "point cost estimates" of technical systems prove to be estimates in optimism and rest on the underlying assumptions governing the system. The proposed methodology should consider a number of alternative outcomes for a number of systems under self consistant goals and rules.

The second criterion for the methodology is that it portray the application of technologies over a range of mission options. The methodology can represent the candidate approaches over a range of scenarios so as to best compare how each mission option may be accomplished.

Finally, the methodology must provide the basis for a continual examination of options in light of advancing knowledge derived from research and development efforts.

It does not appear that a model or methodology of this type has yet been constructed and applied to the lunar base or other advanced space concepts. The examination of such a methodology may be an appropriate early research topic for a lunar base program. The methodology would not attempt to define an economic justification for the whole program, but rather serve to guide research and development along promising paths offering significant leverage. The outcome of a current activity would be to point out promising areas for early research and development which will lessen uncertainty and allow progress or redirection at key times.

The Role of Entrepreneurial Leadership in Major Programs

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A major project such as a lunar base will never come about without a set of skilled articulate champions whose characteristics parallel those of successful entrepreneurs in business and industry. The dictionary defines an entrepreneur as, "one who organizes, manages, and assumes the risks of a business or enterprise." The skills and objectives required by these people are substantially different than those of the professional scientists, engineers, and managers who will impliment the program once it has begun. The entrepreneur is more generalist that specialist, more salesman than researcher.

For a lunar base program to move forward individuals possessing these characteristics, who can grasp the whole program and possess the vision, dedication, and commitment to move it forward despite inevitable institutional resistances must be located and encouraged. Such individuals will assume substantial personal and professional risks to organize others of special talent or skill. But without them, the program will never occur.

Past studies of major projects (Seamans) point out the indespensible role of the individual facilitater in the success of major endeavors, and the failure often associated with those enterprises lacking an effective articulate champion.

We recommend the lunar base activity place a high priority on locating and encouraging those individuals with the desire, will, and the means of effectively carrying the message and assembling the talent required to move the enterprise forward.

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METHODOLOGY FOR COMMERCIAL LUNAR BASE DEVELOPMENT

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Development of a lunar base could follow a variety of possible scenarios. Scientific, military, social and commercial endeavors have been proposed as justification for the base. Some programs currently under study have included consideration of a lunar base in the context of their long term implementation. Long range planning for such projects as NASA's future Space Transportation System, the manned space station, and various space power systems are giving consideration to lunar base requirements. Although initial operational capability is not contemplated until early in the 21st century, development of macro-projects such as a lunar base requires early planning efforts. While there are obvious military and social implications to consider in the development of a lunar base, this paper will address these issues only in the context of commercial development.

The developers of commercial lunar facilities can gain insight from planning techniques for commercial efforts currently being pursued for such programs as the manned space station, free flyers, and advanced communications satellites. The application of such planning techniques can be relevant to lunar development. The identification and development of potential users of lunar facilities, the analysis of alternative approaches to using a third-party intermediary to stimulate private sector activities, and the development of policies and implementation plans to attract commercial interest in lunar facilities will be discussed, and recommendations for a commercial lunar base scenario will be made.

COMMUNICATIONS AND ADVOCACY DEVELOPMENT FOR A RETURN TO THE MOON

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If a program to return to the Moon is undertaken around the turn of the century, the generation that participates in that endeavor will largely have been born and raised in the era following World War II. Their political, social, and technological realities differ markedly from those of previous generations. These Americans have been immersed in an explosively technological society and have come to accept it as a boundary condition on their lives. For them, the space program has opened the door to infinite possibilities even while it has demonstrated the finitude and fragility of their home planet.

In the year 2000 the Apollo experience will be merely history for many, but space travel will be viewed as a possible personal future. They will expect to contribute to and participate in the settlement of the Moon, not vicariously, but directly. Planners who wish to elicit public support for a new program must be prepared to include the public in the program. The feedback between the planning process and popular involvement is nurtured by the channels of communication.

If return to the Moon ultimately means settlement of the Moon, then we are talking about a complex process whose significance rivals any human undertaking of the past. It cannot be done in a highly programmed environment as we now perform spaceflight. The scope of the enterprise exceeds the ability of specialized technocrats to predict all the requisite technologies and to plan the development in a linear fashion. The wealth of expertise in the vast American industrial base must be tapped in an interactive way. Once again, communications across many diverse professions and fields of knowledge will play a central role in the establishment and growth of lunar settlements.

At the present time the concept of a future lunar program is in an embryonic stage, but the number of listeners and contributors grows daily. As no official programmatic focus exists, the collection and the dissemination of information and ideas is an immediate problem. Since the communication gap exists on two levels, professional and popular, no one channel may suffice.

Traditionally, professional communication occurs by means of journals. However, founding a professional journal is difficult and probably premature at this time. Several interdisciplinary journals do exist which might be suitable, but they generally suffer from limited audiences. The best solution currently appears to be publications from NASA if a responsible organization can be identified.

The popular press for space advocacy is relatively well established but exhibits a diversity of focus. The natural solution would be a newsletter specializing in lunar base news if an adequate base readership can be identified. If the targeted audience of a newsletter were to be the potentially interested professional communities, then editorial discretion would have to be exercised to avoid possible alienation of that audience by a content too high in science fiction.

In summary, communication is an important element of a lunar base program, both in initial advocacy and in its ultimate execution. Any newsletter for lunar base planning should be privately published to maintain flexibility and freedom in editorial policy. The establishment of formal channels for communication will remain difficult until NASA provides a focus for information and research on the various problems.

LUNAR MATERIALS: DOMESTIC USE AND EXPORT; James R. Arnold, California Space Institute, Univ. of Calif., San Diego, La Jolla, CA 92093

People on the moon will certainly use lunar materials. The simplest imaginable uses involve only moving the regolith about: for example, covering a living or working module for thermal and radiation shielding. With a little more ingenuity, a wider range of uses can be achieved. The goal of extraterrestrial self-sufficiency is far off, but the first few steps can be planned now. They are likely to be important in making a lunar base economically feasible, and decisive in the next stage of development.

To exploit lunar materials, we must know what they are and how to use them. We know a great deal about the Apollo landing sites, and something about other regions as well (Williams and Jadwick, 1980). Oxygen, iron, aluminum, titanium, silicon and some other elements are present in the soil in abundance. Volatile substances are scarce, particularly water. Watson et al (1961) and Arnold (1979) have speculated that it may be present in abundance in the lunar polar regions. The question must be settled, and a mission called LGO (Lunar Geoscience Orbiter), if approved, will provide an answer by the early 1990's. The result will influence not only the amount and kind of lunar resources used, but also possibly the site of the base.

The promising uses of lunar materials are those involving large masses and relatively simple technology. For use on the moon, life support and materials of construction are obvious examples. Oxygen, bulk silicate and metals can be used, if suitable extraction methods can be developed. We need processes suited to lunar conditions, with durable equipment and large mass payback ratio (mass of product per unit time/mass of equipment). This problem has been studied for more than a decade, but not intensively (L.P.I., 1983). Examples of promising processes will be given, but more work is needed.

Can lunar industry export materials economically? This is not an impossible dream. The obvious market is in LEO (low earth orbit), where we must now bring up materials out of the deep gravity well of the earth, at a cost well in excess of $1000/lb. We and others are studying the potential for bringing lunar and other bulk materials to LEO, using aerobraking and other new technologies to reduce propellant requirements. The moon's advantage is its low gravity. Energy requirements for removal are a few percent of those for the earth, and launching is easy (compare the Apollo LEM to the Saturn V). Its disadvantage is the requirement to bring processing equipment from earth, at first. We must also develop the appropriate technology.

In the longer run, more of the materials and energy needed in space can be provided on and from the moon, as knowledge and productive capacity grow. As this process takes hold, a lunar base can serve as the launch site for more ambitious ventures, to Mars, to the asteroids, and beyond. If that happens, lunar resources will contribute to making these dreams come true.

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THE EVOLUTION OF CELSS FOR LUNAR BASES

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A self-sufficient Lunar base will be required to support its human occupants with as little reliance on resupply as possible. Ideally, a life support system for a lunar base will need only energy, and be capable of generating all of the food, oxygen and water needed by the personnel. It should also be capable of utilizing all of the waste materials generated, including carbon dioxide, and of recycling them to regenerate consumables. NASA's Controlled Ecological Life Support System (CELSS) Program has the objective of investigating the scientific and practical aspects of a life support system based on biological regeneration of waste materials.

An experimental bioregenerative life support system, capable of fully supporting 2 crew members, is being considered by the CELSS program for attachment to Space Station in 1998. This module will be launched after about 5 years of intensive experimentation on various CELSS subsystems in the Space Station. A similar module, if dropped gently on the lunar surface, could function as a life support system, even in the early phases of lunar exploration, provided sufficient power is available.

Evolution from a small, simple life support system to a large lunar agricultural CELSS can occur in stages. Some essential elements for growth include: 1.) development of lunar resources to allow construction of plant growth chambers from lunar materials; 2.) development of the ability to extract some of the required life support materials from lunar sources (e.g. oxygen) 3.) a power supply sufficient to support the needs of plant growth and system operation; and, 4.) development of strategies to meet life support requirement within the constraints of the 336 hour lunar day, and the available power supply.

Of these needs, the most crucial is that for adequate power. CELSS will depend upon the growth of higher plants, algae and perhaps small food animals, in environments stringently controlled to permit maximal food production per unit of power. The indirect use of natural light during the day (through light-piping) for photosynthesis is feasible, but the day length is not sufficient to permit the maturation of food crops. Stored (battery or fuel cell), nuclear, or solar-electric power transferred from polar regions, will be necessary to maintain CELSS operation. Extensive automation of cultivation, harvesting and food preparation activities will also be required, which will demand development of artificial intelligence and robotics techniques.

LUNAR BASE DESIGN. Peter Land, Ill. Inst. of Tech., Chicago 60616

The thrust of this presentation will be to discuss concepts and methods for lunar building. Plenty of schemes have recently been published depicting extensive futuristic lunar cities and buildings but these proposals are rarely accompanied with hard technical information on how they are to be realized and what materials are to be employed in a very difficult operation. They are generally out of scale with realities and when compared with conventional terrestrial building, involve the deployment of hundreds of people and many tons of materials, components and heavy equipment in their erection and so are not appropriate, at this time. A realistic approach to design is now required reflecting the program time frame./ The Los Alamos workshop last April showed how challenging lunar building will be and to start this soon we must define and concentrate on the central ideas now, so that the long process of modeling, development and testing concepts, methods and materials can be initiated. This paper will therefore discuss the potential of various concepts for implementation after the camp stage of the base and define research areas./ The lunar buildings will include all general and specialized base functions for living, scientific and experimental work, assembly and production, maintenance, mining, transport, agriculture, etc. and therefore spaces will be required of different dimensions. The wide range of functions indicates several environments: a) pressurized and shielded, b) shielded only, c) pressurized only, d) and "shaded." This requires a building complex of differentiated forms serving the various functions. However, the possibility of one, or two, pressurized envelopes housing all functions remains a possibility. Its disadvantage is that a stray meteorite could perforate the membrane and endanger all functions, assuming inside shielding. This risk could be reduced by a triple-walled envelope and eliminated if the envelope is under the shielding./ The range of environments indicate a separation of shielding and pressurization, at this stage. Pressurization would be provided by flexible structures using kevlar, mylar or nylon materials in combination with mesh and cable reinforcement. Some ridged members would be needed. The maximum dimensions of such structures collapsed would be governed by the payload bay dimensions of the transport vehicle. At a later stage pressurized enclosures might be built using materials derived from regolith which will be discussed in the paper./ Current theory shows that entirely safe shielding for lengthy presence on the lunar surface is best provided by about 2.0 meters of regolith mass. However, other shielding alternatives should be studied before deciding upon heavy regolith. With 1/6 of earth gravity lifting energies are considerably reduced, but still remain substantial if wide spans are employed. The concepts for shielding are: a) Regolith lifted and dumped onto fabricated raised platforms or arches, b) regolith pushed onto platforms fabricated flat on the lunar surface and afterwards elevated by pneumatic or mechanical means, c) or trenches excavated by dragline-scoop, platforms assembled in excavations and regolith pushed over. The system selected must be that which uses the least energy and the lightest equipment and power modules for moving bulk regolith./ When the most appropriate pressure and shielding structures have been developed, ways must be found to link these together to form the lunar base complex and all its functions, which must be planned to take into account future expansion in rational stages particularly in relation to communication./ The psychological dimension of the entire complex must be considered from the outset and the accumulated experience of long-term habitation in sealed environments, such as submarines, fully utilized.

LUNAR INDUSTRIALIZATION AND SETTLEMENT - BIRTH OF POLYGLOBAL CIVILIZATION

by Krafft A. Ehricke, Space Global Co., La Jolla, CA

The paper presents all aspects of the development of the first extraterrestrial world in this solar system - Earth's sister planet - with the two basic advantages of proximity and closer resemblance than Earth to other accessible surfaces in the solar system. Thus, Moon is an invaluable proving & testing ground for subsequent industrial developments and settlements elsewhere in the solar system. The fact that this can be done without first investing heavily in the infrastructure of adequate interplanetary transportation and still have to accept the heavy costs and operational risks involved in comparatively much longer transfer times and times between launch windows (also for Apollo asteroids), render Moon not only the logical choice as first target for world development, but alsolend investments more direct relevance and reduce their size and their return times by orders of magnitude. In addition, its comparative proximity gives lunar development early and high benefit relevance to terrestrial humanity and the development of cislunar space, creating mankind's first Open World.

Lunar development conceptualization is the first concrete application of the principles of the author's evolutionary philosophy ofthe Extraterrestrial Imperative in the 1960s. It led to the definition of 3 interlocking phases: Exoindustrialization [capability of productive existence in the new environment(s)]/ Exourbanization [capability of establishing large-scale settlements and extraterrestrial civilization to the extent to which it can be underwritten by industrial and biotechnical productivity]; Extraterrestrialization [a prolonged process of socio-psychological adjustment and anthropological divergence based on integration and further evolution of the first two phases, manifesting itself in the physiological, anatomical, immunological, esthetic and general culturalsectors].

Five interlocked development stages(DS) are defined. In the first, exploratory stage, further synoptic prospecting is done with unmanned probes. In DS-2 a space station is established in close orbit, serving as habitat and laboratory, operations center for surface missions and training center for ground personnel, descending to start and maintain automated laboratories and pilot facilities mailed 1-way from Earth. One of these is a small O_2-extraction facility, sized to provide gaseous O_2 for Moon Ferry and space station. In DS-3 large-scale industrial production begins in the nuclear-powered Central Lunar Processing Complex "Cynthia" at the far western equat. Oc. Procellarium, whose location choice will be discussed. In DS-4 the industrial capacity is diversified through establishment of Feeder Stations in certain more distant metallogenic provinces. These DS lead to the establishment in DS-5 of Selenopolis, self-sustaining lunar civilization, founded on a powerful fusion energy base. Each DS lays the economic base for the succeeding one, in fact, is its prerequisite and leads from today's Moon to tomorrow's selenosphere -- the integration of technosphere, sociosphere and biosphere. Progress during all DS is presented in terms of these three spheres (industrial productivity and capability, markets, transportation, power, food production, construction, population size, gross lunar product indicators, socio-anthropological and political-institutional developments). The supply of a growing cislunar market by an advancing lunar industry in DS-3 through DS-5 is described. Advanced industries include the Soletta industry for Earth and Moon and the production of He-3 and H_2 by means of steady and detonative fusion industry. In DS-4 begins the build-up of a Soletta reflector swarm in L-1, eventually reaching a size of 120,000 km^2, illuminating at lunar night a 200,000 km^2 area around Sinus Medii for agricultural and biospheric production ("Novaterra"). Biospheric Novaterra and technospheric Cynthia are the two pillars on which sociospheric Selenopolis rests.

RADIATION TRANSPORT OF COSMIC RAY NUCLEI IN LUNAR MATERIAL AND RADIATION DOSES R. Silberberg, C. H. Tsao, J. H. Adams, Jr., E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D. C. 20375 and John R. Letaw, Severn Communications Corporation, Severna Park, Md. 21146

The radiation environment on the lunar surface is inhospitable: There is no radiation-absorbing atmosphere nor an overall magnetic field that deflects charged particles. The annual dose equivalent due to cosmic rays at times of solar minimum is about 30 rem. Nor is the lunar surface protected from solar flare particles; at energies above 30 MeV, the dose equivalent over the 11-year solar cycle is about 1000 rem, most of those particles arrive in one or two gigantic flares, that last only about 2 days. These doses greatly exceed the permissible annual dose--0.5 rem for the general public and 5 rem for radiation workers. For permanent lunar residents, it is necessary to construct shelters several meters below the lunar surface. At moderate depths below the lunar surface (< 200 g/cm^2) the flux of secondary neutrons exceeds considerably that in the upper atmosphere. This comes about because cosmic ray interactions with lunar material (that contains many nuclei heavier than atmospheric N and O) generate many more neutrons in the nuclear evaporation process. The annual dose equivalent due to neutrons is about 20 or 25 rem within the upper meter of the lunar surface. Since recent experiments show that small doses (an absorbed dose of about 10 rad) of fast heavy nuclei like Ar and Fe have a large probability for generating tumors or fetal abnormalities, we shall present the attenuation rate of heavy cosmic ray nuclei in tissue and in shielding material at the lunar surface. The dose equivalent due to gamma rays generated by nuclear interactions near the lunar surface is only of the order of 1% of that due to neutrons. However, gamma ray line emission from excited nuclei and nuclear spallation products generated by cosmic rays near the lunar surface is of considerable interest: these lines permit the determination of lunar composition with electronic counters.

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TITLE: A Sensitive Method for Detection of Genetic Change in Astronauts During Spaceflight Missions.

A major problem in the detection and measurement of potential genetic damage incurred from exposure to low levels of ionizing radiation or carcinogens has been the lack of sensitivity of the assays used. Due to this constraint, these assays are prone to yielding false negative results. We are in the process of developing an exciting new system which is several orders of magnitude more sensitive than older methods. It relies upon a vastly increased DNA target size for its greater detection power.

Genetic damage is now being measured by assaying changes in small, localized DNA regions of low reiteration frequency which consitute less than 0.001% of the human genome. Over 25% of the human genome, however, consists of moderately to highly reiterated sequences known collectively as 'repetitive DNA'. These repetitive sequences are present in 10 to 500,000 copies per genome. We have constructed repetitive DNA sequence libraries using recombinant DNA techniques and have isolated and characterized individual repeating elements which represent 75-90% of the mass of human repeats. Nearly one third of the repeats in our libraries are organized in human DNA in such a way that a series of discrete bands are produced on an autoradiogram, following digestion of cellular DNA with restriction enzymes, separation of the fragments by electrophoresis, and hybridization with a radiolabeled repetitive sequence probe. Using such probes, it is possible to assay total human DNA for structural changes during or following exposure to the space radiation environment. Qualitative and quantitative changes in the particular repetitive sequence 'family' being analyzed result in changes from the normal band pattern. In this way, many mutational changes such as point mutations, deletions, and rearrangements, as well as DNA-DNA and DNA-protein crosslinking can be detected. To determine the lower limits of detection in this assay, we are exposing human cells to radiation from high LET, low LET, and ultraviolet light. Preliminary results indicate that DNA damage and potential damage repair can be observed at X-ray doses lower than 5 rads.

The effect of the space radiation environment on human beings is a crucial risk factor whose magnitude must be determined to effect the safest possible establishment of long term space installations. Our method for measuring the effects of the space radiation field on astronauts' cells offers many advantages. Blood samples of one to ten mls can be drawn from crew members at intervals and frozen in shielded storage containers for later analysis. Using tiny amounts of human blood, thousands of human DNA sequences can be assayed for changes using a single cloned repetitive probe. By using more and different probes, up to 10% of the human genome can be assayed at one time with this new method. Dosimetry data from previous missions [Benton <u>et al.</u> (1984) <u>Science</u> 225, 224-226] indicate that the radiation doses used in our system fall well within the range of doses received by astronauts during spaceflight missions.

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AEROSOL DEPOSITION ALONG THE RESPIRATORY TRACT UNDER REDUCED GRAVITY CONDITIONS, B.E. Lehnert, D.M. Smith, L.M. Holland, M.I. Tillery, and R.G. Thomas, Los Alamos National Laboratory, Los Alamos, New Mexico. 87545

The respiratory tract acts like a filter in that significant fractions of an aerosol present in inspired air is removed during its movement into and out of the airways during breathing. Under normal conditions, four rate mechanisms are active in this filtering or deposition process: 1) inertial impaction, 2) interception, 3) diffusion, and 4) gravity-dependent sedimentation. With regard to the latter process, the distance a particle will travel along a circular tube, such as a bronchial airway, will be directly proportional to the velocity of the particle due to air flow and inversely proportional to the terminal settling velocity of the particle due to gravity. Sedimentation is the predominant deposition process in the mid-and peripleural airways and in the transitional region of the lung parenchyma; it is the dominant deposition factor for particles within the 0.1-4 μm size range, although it affects the deposition of all particles >0.1 μm dia. Existing empirical data generally complement aerosol deposition predicted from lung models incorporating the different depositon processes. The former data have generally been obtained indirectly or by inference from lung clearance studies. We are presently designing a space experiment to obtain direct information on particle deposition in the lung at reduced gravity, and to determine the quantitative signficance of the sedimentation component inherent to all lung deposition models. In a preliminary, theoretical study, we have employed a modified version of the aerosol deposition model used by the Task Group on Lung Dynamics (International Radiological Protection Commission) to estimate the effects of zero gravity on the deposition of particles ranging from 0.01-10 μm geometric diameter (density-1 or 2) in the human lung. An approximately five-fold reduction in the efficiency of collection of particles $\geq$ 1 μm, regardless of density, occurred in the pulmonary region. An assumption inherent to the lung model is that the collection efficiency of particles in any region of the lung is equivalent during inhalation and exhalation. Our findings are directionally similar to those of Knight, Couch, and Landahl (JAMA 214:513, 1970), who studied particle deposition at 1/6 x gravity by employing a deposition model incorporating the above assumption. We anticipate our deposition studies in space will provide direct information on the importance of the sedimentation component of particle deposition at 1 x gravity, and identify target sites along the respiratory tract for shuttle and lunar base associated aerosols (dust, microorganisms, dander, flatus, electrical fires, etc.).

SPACE CYTOMETRY FOR HEALTH MONITORING

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Monitoring the health status of space station and lunar base residents will provide first hand knowledge of physiological changes. We propose to develop a flow cytometric based set of protocols for peripheral blood monitoring. These measurements will provide cellular, chromosome, and hormone level information. In addition, a computer based multiuse flow cytometer designed for these measurements will be developed for use in space. Flow cytometry is a maturing technology which provides the capability to measure a variety of properties of large numbers of cells, chromosomes or other small objects.

Hematology: Using flow cytometry, we will be able to monitor the hematological status of an astronaut. These tests include quantitation of the number, type (including subsets) and size distribution of circulating blood cells. Such automated white blood cell differential counts will utilize specific monoclonal antibodies for the different white cell types.

Immunoassay: Levels of circulatong hormones and enzymes are clinical indicators of an individuals health status. For example, elevated levels of creatine kinase are indicative of a recent heart attack. A new fluoroimmunoassay having high sensitivity and excellent precision has been developed. The assay employs relatively large (1-10 micron) non-fluorescent microspheres and very small (0.1 micron) fluorescent microspheres. In the assay, soluble antigen (known and unknown concentrations) is incubated with the antibody coated large spheres followed by the addition of the small fluorescent spheres. The small spheres are antigen coated for the competitive binding assay or are antibody coated for the sandwich assay. After equilibrium is reached, the fluorescence distribution of 5,000 large spheres is measured using the same flow cytometer that will be used for the hematological monitoring. Prototype assays have achieved sensitivities of 10^{-12} molar for the competition assay and 10^{-14} molar for the sandwich assay. This technology will be useful for the monitoring the endocrine status of astronauts.

The measurements described above can all be performed by a new generation of flow cytometer. A specially designed system having low power requirements will be able to measure cell volume by resistance, multicolors of fluorescence and possibly even perform some image analysis. It will require a new design to incorporate a compatible excitation light source, to achieve the sensitivity necessary for the immunofluorescence measurements, to provide ease of operation through microprocessor control and to provide the capability for remote system diagnosis.

Towards the Development of Nuclear Magnetic Resonance Metabolic Imaging for the Non-Invasive Monitoring of Human Performance Prior to-, and Post-spaceflight Missions. Laurel O. Sillerud, LS-3, MS M886, Life Sciences Division, Los Alamos National Laboratory, University of California, Los Alamos, New Mexico 87545.

Nuclear Magnetic Resonance (NMR) methods offer distinct advantages for the monitoring of humans without the use of invasive procedures. These include the ability to determine the physiological and biochemical status of organs and tissues in real time, without the use of ionizing radiation or other harmful modalities. When NMR spectroscopy is combined with the well-developed field of proton NMR imaging a new window will be opened into the body through which it will be possible to view previously unobservable processes of adaptation in humans. Applications of these methods to the study of man's adjustment to the low-gravity environment of spaceflight and lunar habitation will provide, for the first time, a more complete description of the details of the mechanisms involved.

We propose to utilize the full range of biological NMR technology to probe the distributions, amounts, and time dependences of the NMR-visible metabolites within the human body during prolonged missions. Of primary concern is the development of methods which will combine NMR imaging capabilities with those of the more highly-developed spectroscopic techniques in order to produce real-time images that will reveal not just the structure of the interior of the human body, but will show, for the first time, full images of the functional activity of organ systems, such as the brain or heart. This is presently possible to accomplish through the means of phosphorus-31 chemical-shift imaging, but with imaging times on the order of hours. Standard proton chemical shift imaging reveals only the distribution of abundant chemical species such as water or triacylglycerols. We will discuss the possibilities for extending proton chemical shift imaging so that it can provide information with respect to the time-dependent distributions of metabolites like lactate or neurotransmitters. The key feature of this new approach is the use of multiple-pulse spectral editing techniques which can be used to produce images of selective metabolites with excellent time and spatial resolution.

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EXOBIOLOGY EXPERIMENTS AT A LUNAR BASE:

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Understanding the origin, evolution and distribution of life on Earth and throughout the universe requires spaceflight data and extraterrestrial observations to verify theories and extend ground-based research findings. Elucidation of these complex processes has been greatly facilitated by planetary mission data (Viking, Voyager), observations of extraterrestrial phenomena (interstellar molecules, comets, planetary atmospheres, SETI), and analysis of extraterrestrial materials (lunar samples, meteorites, cosmic dust). The lunar base would provide an enhanced capability to conduct a variety of additional Exobiology experiments that are either not possible, or cannot be done optimally, on Earth. These experiments generally fall into four categories: (1) Observational Exobiology. Characterization of the forms, abundances and reactivities of the biogenic elements (C,H,N,O,P,S) and their compounds throughout the cosmos is required to establish conditions necessary for the synthesis of more complex organic material. Telescopes on the far side of the Moon would be used. Of substantial interest are frequencies not accessible from Earth because of terrestrial atmospheric and radiofrequency interference. Major targets include planets, moons and comets, the interstellar medium, protostellar nebulae and molecular clouds. In addition, the search for microwave signals from intelligent civilizations could be greatly facilitated, (2) In situ Exobiology. Effect of the space environment, especially solar radiation, on both prebiotic and biotic processes is not well understood. Key experiments include surface chemistry of organic molecules exposed to the space environment for prolonged periods, realistic simulations of planetary atmospheric chemistry, and survival of terrestrial microorganisms, (3) Cosmic Dust Collection. Organic analysis of uncontaminated and undamaged interplanetary and interstellar dust, and characterization of its source, would clarify the nature and extent of organic syntheses beyond the Earth. In addition, examination of extraterrestrial material for evidence of self-replicating structures would be a direct test of the panspermia hypothesis, (4) Lunar Analyses. Comprehensive chemical analyses of carefully selected samples may provide insight into the process of chemical evolution during formation of the solar system. Finally, detailed analysis of the crater record may be relevant to understanding the effect of impact events on the rate and direction of biological evolution. Experiments such as those described in this paper are not only of great scientific importance to the exobiological community, but many of these objectives are also of substantial interest to planetary scientists and astrophysicists.

RAPID IDENTIFICATION OF INFECTIOUS MICROORGANISMS AT A LUNAR BASE. G.C. Salzman, W.K. Grace, D.M. McGregor, and C.T. Gregg. Los Alamos National Laboratory, MS M888, Los Alamos, NM 87545.

The spread of an infectious disease caused by pathogenic bacteria or viruses could seriously degrade the effectiveness of lunar base personnel and even necessitate their return to earth for treatment. Present diagnostic procedures often require lengthy culturing and many hours or days may pass before the infectious organism is identified. Rapid detection and identification of the infectious agent directly from a clinical specimen such as a throat swab would permit immediate treatment with a specific antimicrobial agent and more rapid recovery of the lunar base team member than if a broad spectrum antimicrobial drug was used.

We are developing several clinical instruments for rapid identification of microorganisms using a technology we have called Multiparameter Light Scattering (MLS). In MLS a sample is illuminated with alternately left and right circularly polarized light. The asymmetric macromolecules in a virus or bacterium preferentially scatter one handedness of the circularly polarized light more than the other. Using this technique we have obtained remarkable discrimination among a wide variety of microorganisms. The basis of the discrimination may be that the higher order organization of the nucleic acids (e.g., supercoiling of DNA) is different for different species of bacteria and for different types of viruses. The polarization information in a beam of light can be represented as a four element vector called the Stokes vector and the effect of the scattering from a bacterium or virus can be represented by a 4 X 4 matrix called the Mueller matrix. The instruments we are developing measure simultaneously 8 elements of this matrix. These elements include the differential scattering of vertical and horizontal polarized light and the differential scattering of left and right circularly polarized light, the scattering analog of circular dichroism. One of the instruments makes measurements on virus suspensions and the other is a flow cytometer designed for rapidly making the above polarization measurements on the heterogeneous population of bacteria found in clinical specimens. This work has been reported in several recent papers (1-3) and was performed under the auspices of the U.S. Dept. of Energy. The work was supported in part by the National Institutes of General Medical Sciences Grant No. GM26857 and the National Flow Cytometry Resource.

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EFFECT OF LUNAR FINES ON ESCHERICHIA COLI (BACTERIUM). Karl R. Johansson, Department of Biological Sciences, North Texas State University, Denton, 76203

Revived interest in a return to the moon, with the intent of establishing an operational lunar base, points to the need for further investigations of the effects of lunar soil on living forms, and *vice versa*. To this end, the effect of a sample of mature lunar fines (no. 10084.151) recovered by the Apollo 11 mission, and well characterized chemically and physically, upon growth of the common intestinal bacterium, *Escherichia coli* (strain ATCC 25922), was studied. In one preliminary experiment, 1,147.6 mg fines were leached in a polypropylene bottle with 50 ml 0.01 M salicylic acid stirred in a boiling water bath for 8 hrs. and at room temperature for 40 more hrs. Various proportions of the leachate were admixed in small glass test tubes with a dilute, nutritionally-adequate mineral salts-glucose (MSG) medium containing 50 mg of ethylenediamine tetraacetic acid per liter. The pH of both the medium and the leachate was adjusted to 7.0 prior to sterilization by filtration. Following inoculation with a washed suspension of *E. coli* cells recovered from a young culture in the MSG medium, growth was measured turbidimetrically at intervals over a 10-day period. Growth was substantially enhanced at all concentrations of the leachate. In another experiment, lunar fines were added directly to 5 ml of the MSG medium and the tubes were sterilized by autoclaving (121°C, 15 minutes). Growth of *E. coli* in these tubes was somewhat depressed during the first 18-24 hours; thereafter, growth was increasingly stimulated at each level of lunar material (11.5, 20.4 and 50.9 mg/tube). Thus, under these conditions the fines were initially inhibitory and subsequently stimulatory to the bacteria. Small quantities (5.6, 14.2 and 20.9 mg) of fines placed upon the surface of freshly-seeded nutrient agar (Difco) on a Petri plate had no observable effect upon the subsequent growth; however, a drop of neutralized leachate placed upon such plates produced, upon incubation, a circular area of dense growth, greater than that found on the rest of the plate. Chemical analysis of the leachate revealed the principal elements to be, in mg/liter; iron (51), calcium (47), aluminum (44), silicon (24), titanium (5.7), sodium (4.1), boron (1.9) and phosphorus (1.2). Which elements, or combination of elements, were responsible for the biological effects was not determined. Those in amounts less than 1 mg/liter (e.g., Zr, V, Zn, As, Cd, Br, Sn, Pb, Cu, Mb, Cs, Cr, Ni) also could have influenced growth of *E. coli*.

FEASIBILITY OF AUTOMATED LUNAR MINING EQUIPMENT

by

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Advances in such diverse fields as industrial automation, autonomous planetary rovers, and deep space probes as well as in artificial intelligence and high performance low cost micro-computers support a synthesis of these techniques to create mobile construction and mining robots. Current work being sponsored by the Army, Air Force, and Defense Advanced Research Projects Agency (DARPA) is paving the way for the development of commercial terrestrial and extra-terrestrial mining equipment.

Before a technology is developed to the state of being readily available, there must exist an economic need. The type of work involved in mining, whether on earth or the moon, is in harsh and/or hazardous environments and involves repetitive tasks. These are the very same reasons often cited for using robots. Also the very high cost of life support will make it economical to use robots as associates, gophers, and assistants to humans. Consequently, it appears that both the need and economic incentives needed to spark the development of mining robots exist.

The results of a review of the current research being done in the field of mobile robotics along with the enabling technologies are presented. Preliminary system requirements are outlined as well as a possible time frame for development. . It appears that the capability of producing robotic construction and mining for use on the moon will exist a number of years before a lunar base is started.

FUEL CELL PROPULSION SYSTEMS FOR LUNAR SURFACE VEHICLES

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Fuel cells have previously been used in space as electric power sources for manned spacecraft. Department of Energy programs have focused on developing fuel cells for stationary utility and electric vehicle power plants. This paper will focus on the application of fuel cells for lunar surface vehicles. Benefits of efficiency, energy density, and environmental acceptability within closed structures will be described as well as possible extensions of the ongoing DOE vehicular program to lunar applications. Particular emphasis will be given to proton exchange membrane (PEM) fuel cells, for example, the General Electric solid polymer electrolyte (SPE) technology.

The basic construction of the fuel cell is rather simple, consisting of two electrodes separated by an electrolyte. In operation, a fuel such as hydrogen is passed over the anode, where it is electrochemically oxidized, generating electrons. The electrons flow through the external circuit to the cathode where they combine with an oxidant such as oxygen, to form a reduced product (water in the case of the hydrogen-oxygen cell). The electric circuit is completed by ionic conduction through the electrolyte.

The key element of a PEM fuel cell is the electrolyte, which is a sheet of polymer plastic (sulfonated fluorocarbon) that is 5 to 10 mils thick. The material used in the SPE cell is Nafion, produced by DuPont. Nafion is essentially a sulfonated analog of teflon with very similar physical properties. The SPE fuel cell technology was developed primarily for space applications, and most SPE systems operate on pure hydrogen and oxygen. The SPE technology has also been developed for water electrolysis to break water into hydrogen and oxygen. SPE fuel cells have demonstrated greater than 50% efficiency as well as operational lifetimes in excess of 60 000 hours. Key features of the PEM fuel cell are no free corrosive liquids, insensitivity to differential gas pressures, and a specific weight of 7 to 15 lbs/kW. When combined with a source of electricity (nuclear, solar, etc.), the PEM fuel cell-electrolyzer combinations, therefore, provide an excellent mobile power source-mobile fuel producer for lunar vehicles; range can be virtually unlimited because of the ability to increase the fuel storage on board and rapidly refuel (as opposed to batteries). Hydrogen, oxygen, and water are also well understood and routinely handled by NASA. DOE fuel cells for transportation programs are currently striving to reduce the cost and improve the performance level of PEM fuel cells, and it is expected that benefits achieved by that program will enhance the utility of fuel cells for lunar propulsion systems. DOE programs use methanol as a fuel and have stringent performance requirements because of the weight and aerodynamic drag of earthbound vehicles. Systems particularly designed to handle vehicular transients are currently under study as well as improved catalysts (lower costs, more efficient) and alternative membranes to Nafion.

NUCLEAR ENERGY - KEY TO LUNAR DEVELOPMENT

by

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ABSTRACT

The Moon will play a very central role in man's exploitation of cislunar space. Energy, especially nuclear energy in the form of advanced radioisotope and fission reactor power systems, will play an equally major role in any lunar development program. This paper explores the relationship between man's successful return to the Moon as a permanent inhabitant and the use of nuclear energy. It is done within the context of a five stage lunar development scenario. The technical discussion extends from the use of radioisotope-powered vehicles for mineral resource exploration and automated site preparation; to the reactor-powered early manned bases in which scientific investigations and prototype manufacturing projects are undertaken; to the rise of a fully autonomous lunar civilization, nourished by its own nuclear fuel cycle. If the use of nuclear energy is properly integrated into lunar development strategies, it will not only greatly facilitate the industrial development of the Moon, but may also represent a major lunar industry in itself. It is distinctly possible that very large nuclear-powered communication platforms located throughout cislunar space will be designed, constructed and fueled by future lunar inhabitants. The same may be said for the advanced multimegawatt class reactors that will power electric propulsion vehicles, carrying human explorers to Mars and sophisticated robot explorers to the outer reaches of our Solar System and beyond. The Moon is humanity's geteway to the Universe - and nuclear energy is the technical key to that gate!

SPACE NUCLEAR POWER - ENABLING APPLICATIONS FOR LUNAR BASING

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The feasibility of establishing and maintaining a lunar base depends on the availability of ample power. Power is required for two distinct operations, the energy required to transport materials from the earth to the moon and the long-term energy needed for lunar operations. Space nuclear power can provide the power to meet both of these requirements.

A nuclear reactor system could provide power on the lunar surface independent of solar orientation. The system would be sized to provide power both during the day and night cycle. Current space power systems in the SP-100 program are being designed for operation at electric power levels up to a megawatt. With relatively minor modifications, these SP-100 systems can be used on the lunar surface. These modifications include the use of lunar materials to provide the radiation shielding, and also the incorporation of the waste heat from the reactor into an integrated thermal management system for the lunar base. Requirements for power levels significantly above 1 megawatt can be met either by growth versions of the SP-100 systems or by multiple 1 megawatt units.

The transportation of large masses of materials from low earth orbit to a lunar base is an extremely energy intensive operation. Space nuclear propulsion will significantly increase the amounts of material that can be transported. The specific impulse of nuclear propulsion systems is from two to ten times greater than for chemical systems. This reduces the amount of propellant that must be expended and greatly increases the effective mass that can be transported to lunar base.

There are two alternative methods for using nuclear propulsion. These are nuclear rocket propulsion and nuclear electric propulsion. Both methods have features that are potentially enabling for lunar bases. The nuclear rocket can propel large masses to the moon rapidly. Nuclear electric propulsion can propel even larger masses to the moon at the expense of a longer trip duration.

This paper will discuss applications both for prime power on the lunar surface and for nuclear propulsion from earth orbit to the moon. The technology requirements to implement space nuclear power systems will also be discussed.

NUCLEAR POWERPLANTS FOR LUNAR BASES

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Preliminary pre-project studies are in progress leading toward development of a 100 kW electrical output powerplant for use in space. Four different powerplant concepts are under consideration, one of which will ultimately be selected for development. Current system design concepts are intended for use in space and, for a variety of reasons, would not be completely -suitable for use on or beneath the lunar surface. However, the small compact reactor and long-life energy conversion and control technology and designs could readily be adapted for a lunar base power plant.

Initial design life of SP-100 systems is 2 years with a goal of 7 years. Longevity of this level would be most appropriate to and would be an enhancement of the reliability of a lunar base. Use of indigenous lunar materials for shielding would reduce one of the major mass components of a man rated system and would render a 3000 kg mass allocation for a lunar version of a 100 kWe output system most reasonable. Costs of lunar transport will continue to put a premium on low mass.

Probably the main advantages of a nuclear powerplant for a lunar base are operational. Not only is it compact and easy to transport and emplace but it provides around-the-clock continuous operation on the lunar surface regardless of day/night cycles. As a result of the efficiencies inherent in the thermal-to-electric conversion process considerable "waste heat" is produced. In the unmanned space application this heat energy is indeed usually "waste." In the lunar base situation however this heat energy left over from the thermal-to-electric conversion process may be quite useful. Applications range from warming facilities at night to providing heat energy to a variety of materials processing applications.

LUNAR POWER SYSTEM

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Growing dependable supplies of economic power must be provided on the moon and throughout cis-lunar space to underpin a growing economy in space. Earth's moon appears to provide a ready natural platform for this. We can use it to dependably convert solar power to electricity and microwaves for use on the moon, distribution to users throughout cis-lunar space, and possibly to receivers on Earth.

We now know on the basis of extensive post-Apollo research that in many respects the lunar surface is an ideal place for the construction of large solar power systems. There is no air or water and virtually no mechanical activity (wind, rain, hail, floods, seismic waves, wind-blown dust, animals or humans). Large area collectors (e.g., mirrors) or direct converters (e.g., amorphous silicon photovotaics) can be made of extremely thin, segmented devices situated directly above the lunar surface. Engineering materials (lunar soil, silicon, glasses, iron, aluminum...) obtainable from common lunar soils can be used to manufacture most components of a solar power system and provide protective environments for critical components. Lunar materials are extremely resistive electrically, have very low thermal expansion and conductivity (10 cm below the surface temperature varies less than one degree kelvin), dissipate seismic and impact energy, can protect against solar particles and are stable in the lunar environment. Power collection wires and many other devices can simply be buried.

At most locations on the moon, solar power is available for 14 days. Several types of power storage devices can be made of lunar materials to supply modest power during the 14 days of lunar night. Eventually, mirrors of very low areal mass and made primarily of lunar materials can be placed in orbit about the moon to efficiently provide far larger flows of solar power to dark regions. Characteristics of several lunar power systems will be reviewed.

Doctors David R. Criswell and Robert D. Waldron have studied construction on the moon of power transmission systems composed of segmented antenna systems capable of transmitting (100 km aperture for 10 cm waves) in multiple microwave beams millions of kilometers to mass efficient receivers (1kg/kw) in space or on Earth. Such beams could continuously power industrial facilities, electric rockets, or space stations directly or via reflectors. Characteristics of such multibeam systems will be explored. Major research needs will be summarized.

LUNAR BASE - AN INTERDISCIPLINARY STUDY OF THE MOON'S INDUSTRIAL AND RESEARCH POTENTIAL. D. A. Draeger, K. W. Heien, T. F. Tascione and R. H. Bloomer, Department of Physics, USAF Academy CO 80840.

This report considers the technological and economic feasibility of conducting research and industrial operations on the moon and develops a proposed lunar facility to accomplish the selected projects. A result of an undergraduate honors seminar at the United States Air Force Academy, the report first addresses in detail the possible projects that a lunar facility could support. These include mining, pharmaceutical production, ball bearing and integrated circuit fabrication, crystal growth, resupply and reservicing of terrestrial space systems, and basic research. The analysis shows that oxygen mining and basic research are the most economically and technologically feasible projects.

The mining technique recovers oxygen from the regolith using about 7.5 MW of power and manning needs of 10. This power-intensive mining process requires a high temperature hydrogen reduction process, and the final product, water, is then separated by electrolysis. The oxygen is then shipped to earth orbit for resupply of terrestrial space systems.

The base facilities are then discussed with particular emphasis on the research laboratory. The structure has been sized according to a manpower constraint of twenty crew members. Three large, prefabricated cylindrical tanks, covered by 5 m of lunar soil as a radiation shield, will be used as the basic structures. One tank will be devoted to living space, another to research, and the third to mining operations and storage.

The lunar facility will be powered by a high temperature gas-cooled reactor capable of generating 6 MW of electrical energy. A parabolic reflector coupled with a solar oven will be used to generate 2 MW thermal energy in the 1200 K range necessary to accomplish the reduction step of the mining process. The back-up power system will be hydrogen-oxygen fuel cells, using the O_2 and H_2 from the mining process as reactants during an emergency to provide 150 kW of power for up to twenty days.

Transportation is examined in four stages. The shuttle or its derivative will be used from earth surface to LEO, an Orbital Transfer Vehicle will be used from LEO to LLO, a Lunar Lander will serve from LLO to the lunar surface, and some type of lunar rover derivative will provide surface transportation.

Finally, a cost analysis of oxygen production and research was developed. Disregarding initial set up costs, the analysis shows it might be less expensive to produce and ship oxygen to LEO from the Moon than from the earth. The facility set-up will have to be accomplished during solar minimum to reduce radiation hazards, and due to present space suit thermal insulation limitations, the facility construction is estimated to take at least one years time.

A CALL FOR LUNAR ELECTRIC POWER AND CONNECTOR STANDARDS

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This is the appropriate time to begin developing internationally accepted standards for lunar electric power distribution, starting at the consumer interface level. Semi- or fully autonomous electric power sources must be available down to the level of the smallest habitable unit to maximize the ability to function and to survive catastrophes; standard dc voltage levels and connectors will facilitate cooperation to aid people and habitations that have been isoloated. The lack of a worldwide standard for power distribution (voltages, frequencies, and connectors) is a nuisance; a standardized system will allow minimization of redundant devices, increase safety, and maximize productivity.

An international committee should be established to develop a set of standards for lunar electric power distribution. The highest priority should be given to developing standards at the user level, including dc voltages, ac voltages and frequencies, and connectors.

A multifunction connector family should be developed that will make BOTH ac and dc power available to any device or to any module. The powered device or module could select ac or dc power either automatically or manually. Plugs could be developed that would access only ac or dc. However, they should be discouraged because access to multiple power sources offers increased safety that could prove valuable should either power system fail.

The definition of the connector family should allow flexibility. For example, it could provide space for additional buses to be installed to transmit signals between modules and/or devices. If the power distribution block is part of a larger connector specification, in a constant position within the connector, a single, multiple connector package could power and interconnect both modules and discrete devices. This arrangement could increase reliability of systems because it permits a high degree of flexibility, rapid reconfiguration of systems, and access to multiple power sources.

THE LUNAR RESOURCES HANDBOOK

by: The Lunar Resources Handbook Committee
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Lunar resources include all materials accessible to moon-based operations. Lunar samples that have been under intensive study for over 15 years are representative of these resources. More than 380 kg of samples were returned from the moon by the United States and Soviet missions. Although not all of the returned material has been processed for study, those samples that were prepared have typically been studied and re-studied by researchers from many fields. These researchers have examined an extensive suite of physical, mechanical, electrical, mineralogic, petrologic, and chemical properties. The results of these studies are widely scattered through many publications, some of which were of very limited distribution and are no longer available. Many data have never been published at all. There is an outstanding need to compile these data now into a readily accessible handbook format.

This handbook is intended to meet the needs of workers in the life sciences, engineering, chemistry, and the planetary sciences. It will also serve lunar base planners, university, industrial and government scientists, and program managers, and students. To satisfy this broad spectrum of users, the handbook must be compiled in a format that will readily provide access to basic data. Facts must not be masked by speculation.

The proposed outline for the handbook has nine sections:

I) Justification and purpose of the book, including a brief discussion of lunar resources and resource processing.
II) The lunar context. What is different about the Moon? This section will cover terminology, the lunar grid, lunar cartography, remote sensing data, and brief landing site descriptions (Surveyor, Apollo and Luna).
III) The lunar environment. Data on the Moon's atmosphere, gravity, cosmic ray flux, solar wind, dust (including particle charging), thermal environment, and day/night cycles will be compiled in this section. Key absences, including volatile elements, will be described.
IV) Lunar mineralogy and petrology. This section will include data on mineral types, sizes, distributions, and other characteristics. Major differences from terrestrial minerals will be covered, such as track damage and lack of water. Petrologic data will be compiled for the three-fold subdivision of highland, mare, and regolith samples.
V) Lunar chemical properties. Data will be compiled for solids (rocks and soils), gases, surface-correlated components, and chemical variations as a function of provenance and grain size.
VI) Lunar physical and mechanical properties. This section will include data on properties that are mechanical (density, shear strength, etc.), electrical and magnetic, optical, and thermal. Particle and defect distributions and gas-solid interactions will be covered.
VII) An afterword, primarily to identify needed research.
VIII) A glossary.
IX) An annotated bibliography, directing the reader to primary sources and providing summaries of those sources no longer available.

We solicit ideas and suggestions covering the format for this handbook.

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EVALUATION OF LUNAR RESOURCES

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The potential use of lunar resources at a lunar base and to support space operations is a concept which has been discussed recently in some detail. However, the criteria which one would use to evaluate lunar resources in terms of specific sample types or sample concentrates most appropriate for a given application have not been considered in detail. For example, it is usually assumed that lunar soil is the most appropriate starting material for resource utilization. While this may be true for some applications it is certainly not true for all. The evaluation process for lunar resources really consists of evaluating a series of tradeoffs between the resources as they exist on the moon and the amount and kinds of processing necessary to transform them into useful material. Ideally, for each application, there will be one sample type most suitable as a raw material. However, multiple applications may require compromises and tradeoffs so that the most suitable sample type is not always used. Evaluating these tradeoffs requires that a number of properties of each sample type be considered including some rather subtle properties. Examples of some of these tradeoffs for specific samples are given below:

Highland versus mare material. If the proposed application is to produce aluminum from anorthite or titanium from ilmenite then the choice between these two types of material is clear. However there are more subtle distinctions. The finest grained lunar soils are all highland; the mean grain size of typical mare soils are about twice those of highland soils. Consequently, applications requiring fine grained soil such as those related to surface correlated volatiles would best be served by highland soils. However this generalization does not hold for solar wind hydrogen; based on the existing Apollo data base, hydrogen appears to correlates with TiO_2 so that mare soils are richer in solar wind hydrogen even though coarser grained.

Soil versus rock. Soil is generally suggested as a raw material for most application because it is already finely ground and is presumably easy to mine. However soil has a number of disadvantages compared to rock. It varies considerably from place to place in grain size and maturity which is related to surface exposure history. Processes designed for a specific set of sample parameters may not easily handle such variations. Some applications such as concrete aggregate may require a specific and relatively coarse sample size which cannot be easily attained from soil. On the other hand rock, for example basalt mined from flows, can be ground to a constant and predictable size distribution. Soil grains have very complex surfaces affected by radiation, micrometeorites, and glass splashes. These grains can not be easily separated by magnetic or electrostatic methods because their properties are so variable. Conversely, grains from ground basalt should have predictable properties which can be more easily handled by separation and concentration equipment. The tradeoff between ease of mineral separation versus the necessity of grinding the basalt must be carefully evaluated.

Regolith breccias. These breccias, particularly highland breccias, have some of the advantages of both soils and rocks. They are usually immature without the problems of coated grain surfaces, splashed glass and metal associated with mature soils. Yet many of the samples in the Apollo collection are friable and easily broken apart and would probably be easy to mine.

In similar ways, other sample types must be critically evaluated for each application. Given the diversity of lunar material types it might be more appropriate to find a material to fit the process rather than design a process to fit the first material to come to mind, usually "lunar soil".

PETROLOGIC AND CHEMICAL SYSTEMATICS OF LUNAR SOIL SIZE FRACTIONS: BASIC DATA WITH IMPLICATIONS FOR SPECIFIC ELEMENT EXTRACTION; J.J. Papike, Institute for the Study of Mineral Deposits, South Dakota School of Mines and Technology, Rapid City, SD 57701-3995

Over the last ten years a wealth of petrologic and chemical data have been collected on lunar soils. More recently a representative suite of soils from all Apollo and Luna sites has been studied systematically in terms of the chemistry and petrology of various grain sizes; 1000-90, 90-20, 20-10, and <10 µm.[1] Although the motivation for these studies was largely in terms of broad characterization of the lunar regolith and constraints on mechanisms of lunar regolith evolution, the spinoff for potential processing of regolith for specific element extraction is significant. For example, we understand, in great detail, the distribution of the major elements among the regolith components and as a function of grain size. The specific processing technique chosen for extraction may be dictated by these petrologic and chemical systematics.

Figure 1 is a map of the Moon showing the Apollo and Luna sampling sites. Although these sites represent relatively limited coverage of the Moon, we have collected a significant amount of data on the returned samples. Because we have determined the chemical composition of a 14-soil suite from all sampling sites, we know not only the bulk composition of this size fraction (1000-90 µm) but also how elements of interest are distributed among the regolith components. For example, Ti will be located largely in mare basalt fragments and the mineral ilmenite. A decision will have to be made as to whether to process the bulk sample or to separate various soil components first. Our data show that the modal proportion of soil components varies with grain size. For example, the fused soil component (agglutinates plus regolith breccias) decreases with decreasing grain size. Therefore, if one is interested in extracting metallic iron from agglutinates, the 1000-90 µm fraction will be of most interest. The chemical composition also varies with grain size. In most of the soils portrayed, Al_2O_3 shows a pronounced enrichment in the finest fraction. The reason for these systematics is that feldspar (the major carrier of Al_2O_3) is broken down to fine grain sizes more readily than other mineral phases by impact induced comminution.

In summary, although the original impetus for conducting detailed petrologic and chemical studies was largely scientifically motivated, the potential practical spinoff for materials processing on the Moon is great.

Reference: 1. Papike, J.J., Simon, S.B., and Laul, J.C. (1982) The Lunar Regolith: Chemistry, Mineralogy, and Petrology. R.G.S.P., 20, 761-826.

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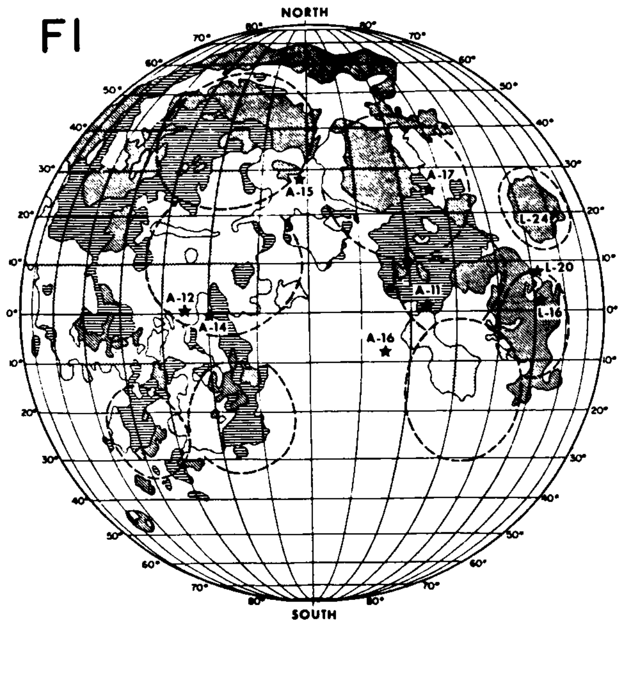

DIVERSITY AND PURITY: KEYS TO INDUSTRIAL GROWTH WITH REFINED LUNAR MATERIALS

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The importance of a lunar base in supporting a space materials industry will depend in large measure on the breadth of refined materials or feedstocks available to manufacture products, structures, and consumables. Although a limited range of applications for raw lunar soil or physically extractable fractions exists and may, indeed, support a sizable commercial traffic, one will remain consigned to "iron age" and "ceramic age" technologies (useful for primitive structures, propellant reaction mass and shielding) until chemically refined products can be generated in practical quantities.

Theoretical and laboratory studies over the past seven years have laid the foundation for a closed-cycle, chemical processing system capable of separating purified fractions of the seven major lunar chemical elements and recovering minor and volatile trace elements used in processing.

The feedstocks available from the processing system can be used to provide high technology alloys and metals and non-metallic materials, ranging from refractories to consumables, to assist in growth of the lunar base and space industrialization by local manufacture of structures and habitats, mechanical, electrical, magnetic, optical, and thermal devices, solar power converters, space radiators, and propulsion materials.

"ON-LINE" SIMULATION OF HYDROGEN AND WATER DESORPTION IN LUNAR CONDITIONS. G. Blanford[1], P. Børgesen[2], M. Maurette[3], W. Möller[2]. [1]University of Houston-Clear Lake, USA-Houston TX 77058; [2]Max-Planck-Institut für Plasma Physik, D-8046 Garching bei München; [3]Laboratoire René Bernas, F-91406 Orsay.

To discuss the feasibility of "mining" the Moon for H_2 and H_2O we must first assess the validity of basic models proposed over the past ~10 yr which describe the accumulation and release of solar wind (SW) related species (D_2^+, He^+) in the lunar regolith (1). To do this we used a chamber developed to investigate the retention in the near-surface range, the diffusion into the bulk, and the release of hydrogen isotopes in metals (2). This chamber has a 40 kV accelerator for implanting ^2D and ^3He ions, a Van de Graaff accelerator for analysis, and an <u>on-line</u> quadrupole mass spectrometer (MS). The MS was used to monitor the simultaneous desorption of D_2 and D_2O from the targets which include terrestrial analogs of lunar materials (simulated lunar glass and crystals of feldspar, olivine, and ilmenite) and two materials which are highly stable against radiation damage (silicon and sapphire).

We are currently investigating the concentration of deuterium as a function of fluence up to saturation, the desorption of D_2 and D_2O as stimulated by ion implantation and thermal annealing (in particular for low temperature desorption peaks possibly effective at "lunar day" temperatures of ~150°), and the effects of helium damage on the thermal desorption peaks and the depth profile of deuterium. So far we have only analyzed feldspar, silicon, and sapphire.

Our results indicate that the present model for the accumulation of SW-hydrogen in silicates like feldspar is not valid. The thermal desorption pattern for D_2 in the three distinct targets has a complex multi-peak structure which is not explainable by the simple diffusion mechanisms so far proposed. Consequently it is impossible both to predict from basic physical principles the lunar reserves of hydrogen and to devise a heating scheme to optimize the extraction of SW-species from lunar materials because at least two key mechanisms for retention of hydrogen in these materials are poorly understood.

Besides helping to constrain models our results also give some information about mining H_2 and H_2O on the Moon. For example the thermal desorption of D_2 at intermediate temperatures (300°C < T < 500°C) both confirms that SW-species can be partially retained at lunar day temperatures and suggests that a low energy heater (possibly solar) could release H_2 and H_2O from mature lunar soils. Moreover by pulsing the deuterium beam we also clearly detected a solar wind "stimulated" desorption of water molecules generating a yield of D_2O relative to D_2 implanted of about 10^{-3}-10^{-4}. This yield could possibly be enhanced during a "hot" solar wind implant effective at lunar day temperatures by generating a velocity distribution for the H_2O molecules which would permit their redistribution to the permanently shadowed regions near the lunar poles. However, concerning other interstellar conditions, both hot (~430 K) and cold (~20 K) implants effective on grains at various astrophysical sites could desorb some interstellar molecules. The effects of hot and cold implants on the desorption yields of D_2 and D_2O will soon be investigated using appropriate target holders.

REFERENCES: 1. For a good review of previous work see Pillinger C.T. (1979) <u>Rep. Prog. Phys. 32</u>, 897; 2. Möller W. (1983) <u>Nucl. Inst. Meth. 209/210</u>, 773.

ROLE OF IRON IN SPACE by S. SASTRI, NEW YORK CITY TECHN.COLL. BKLYN, NY 11201

Ingot iron and alloys of iron offer a source of structural material for building the space infrastructure. Iron is present as a major constituent in lunar soil. Near earth crossing asteroids, also offer a promising resource of iron. All lunar soils contain iron in the metallic form. The maria lavas are rich in chemically combined iron up to 17%. The various extraction processes and the thermodynamics for getting ingot iron and iron alloys will be outlined including the physical and mechanical properties of iron alloys. Methods of producing high purity iron and defect free ultra pure iron are outlined. The manufacturing and fabrication processes of metallic iron and its alloys for building the space infrastructure are discussed.

CARBONYLS: SHORT CUT FROM EXTRATERRESTRIAL ORES TO FINISHED PRODUCTS.

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Past proposals to utilize extraterrestrial ores, especially metals, have emphasized extremely complex and energy-intensive processes to beneficiate low grade ores and to extract, refine, and fabricate products from the metals in them. However, the commercially used gaseous carbonyl processes for both refining and chemically vapor forming structures (not just thin films) through the nickel carbonyl ($Ni(CO_4)$) process, and similar reactions for iron and other carbonyls, may become a catalyst for economical use of extraterrestrial resources. This process is simple and operates at low temperatures and pressures.

Extraterrestrial resources amenable to carbonyl processing include the grains of nickel/iron alloy found in lunar fines and the iron, stony-iron, and stony chondrite meteorites. All these classes, including the lunar ore, are believed to originate in parent asteroids.

The sole reagent used in refining and vapor forming carbonyls is carbon monoxide. It is readily recycled and can be obtained by heating to moderate temperatures nearly all meteorite samples. Carbon, however, is nearly nonexistent on the Moon (barring discoveries at the poles) and would have to be imported for carbonyl operations using lunar ores.

Both the refining and vapor forming processes for iron and nickel occur near one atmosphere pressure and at temperatures easily achievable with passive thermal control. Pure carbonyl-formed nickel structures have a tensile strength of over 100,000 psi; a proprietary doping process of Formative Products Co. brings it over 200,000 psi. After annealing, these structures are nearly free of the intrinsic stress that has limited vapor deposition of structures through other techniques. Nickel vapor-formed products faithfully copy complex mandrel shapes, filling holes and around corners, and can even reproduce high quality polished optics. No parting compound is needed to remove such vapor formed products from their molds.

The simple chemistry and moderate process conditions suggest the carbonyl porcess will be amenable to automation. The space environment will free the process of its two major problems: contamination by air and toxicity of CO and carbonyls if leaked into the environment.

Optimum structure strength is commercially achieved at a deposition rate of 0.01 inch/hr. This suggests a favorable throughput to process equipment mass ratio, especially when compared to traditional metal smelting, refining, and forming industries.

End products of a carbonyl-based space or lunar industry may include structural materials for space bases, antennas, power supplies (perhaps including solar power satellites to ship energy to Earth), as well as structures, optics, and armor for military space systems. A byproduct of such carbonyl processing would be a residue of approximately 50 gm/ton of metal throughput of platinum group and other precious metals. With market values around $10,000/kg these could be profitably shipped to Earth. An extraterrestrial source of these metals would free the U.S. from dependence on Soviet bloc nations and South Africa, which currently supply some 95% of U.S. consumption of these metals.

WHAT ARE THE EASIEST PRODUCTS TO GET FROM SPACE RESOURCES?

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We envision increased commerce and settlement of near-Earth space. This will require substantial material in space for construction, manufacture, and extraction of solar energy. The growth rate of space activities may depend on how cheaply that material can be provided. Use of material resources already in space may offset the high energy cost of lifting them from Earth.

Scenarios have been proposed for use of materials from the Moon, near-Earth asteroids, and even Mars. Most scenarios have presumed availability of a broad range of materials. Few have been restricted to considering in detail extraction of well characterized raw materials known to be present and their manufacture into important, ready-to-use products. There is a dearth of laboratory research to support the validity of most scenarios.

Existing scenarios may eventually prove plausible in a general way. Many cannot be developed in detail because of gaps in our knowledge of materials, exactly where to find them, and how readily they can be mined. We know the compositions of Mars' atmosphere and polar caps and a little about the regolith near the Viking landers. Mars is too distant to provide material for near-Earth space. Near-Earth asteroids have low gravity fields and presumably are the sources of many well characterized meteorites. They can be visited with energy expenditures comparable to or less than that needed to visit the Moon, but at less convenient intervals. However, we cannot today select any asteroid with reasonable confidence of knowing just what material would be found or its physical state.

The only near-Earth resources we know enough about to devise means to exploit are on the Moon, which is also poorly explored except where the Apollo missions landed. Enough was learned from those missions to devise detailed scenarios for resource extraction and use, scenarios which lend themselves to laboratory testing and refinement. If in addition we assume that the simplest products and scenarios will be the most cost effective, some guidelines can be derived for constructing scenarios for testing. These include the following:

Only abundant material at an Apollo site should be considered as usable raw material. Such material should be used as feedstock in "as found" condition, or with minimal high-grading. Only simple, few step, somewhat flexible processes may be used to convert such material to products. Items to be manufactured should be designed to use readily available material, not normally used or most desired material. Components and machinery from Earth should be minimized.

Further exploration of the Moon and near-Earth asteroids should expand the variety of usable "ores," so these restricted guidelines are conservative and pessimistic. Even with these restrictions, numerous metallic and silicate products and oxygen can be produced from bulk soil, mare basalt, or feldspar-rich highlands materials. The simplest scenarios and easiest available starting materials may not be the most cost effective, but seem to be the right choices for initial analysis. Laboratory testing of ideas, followed by scaling up of surviving ones, should be completed before the design for the first Moon base is frozen in. Then, optimum use can be made of lunar material in base construction and testing of more advanced extraction and manufacturing scenarios can be carried out on site.

GETTING READY FOR TECHNOLOGY STUDIES ON LUNAR SOILS

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In preparing for initial lunar base activities, we will need to know more information about the moon's soil. Past studies have concentrated on unlocking scientific secrets of lunar soil. As a result, lunar soil chemistry is fairly well known, but engineering properties and industrial reactions are not as well studied. Apollo soil mechanics and thermal information gathered by early researchers was derived from television, surface photography, measurements using a penetrometer and heat flow probe, and laboratory experiments on core-tube samples. Further laboratory studies can be done in two ways: one way is to make a large amount of well-simulated soil, and another way is to use small amounts of the soil returned on the Apollo missions. The most information can be gained by appropriate use of both methods.

For living and manufacturing on the moon, the following are some areas of soil usage that need to be considered: excavation and structure support, construction materials, thermal insulation/conduction, radiation shielding or reflectivity, use with fluids, volatile extraction, and biological growth medium. Abrasion and coating of equipment are among nuisances to be considered. Associated with each of these areas are physical properties of soil (such as grain surface reactivities, electrostatic and thermal characteristics, slope stability, soil compressibility) about which more information would be desirable. A working group discussion would be helpful in defining important properties to examine.

The lunar samples upon which to make needed measurements are precious; therefore, simulated soil should be used when suitable. Major mineral components and grain size can be simulated with crushed terrestrial basalts. The agglutinates, tiny glass particles constructed from continual micro-meteorite impacts, have not been duplicated experimentally. They contain finely divided free iron dispersed throughout the glass. Radiation damage and solar wind gases are components of soil grain surfaces which have not been simulated in useable quantities. Generally, determination of the physical properties of the small grain surfaces will require measurements made on real lunar soil.

We are reviewing which properties can be investigated with simulated lunar soil (and thereby helping to define a simulant composition) and which properties require real lunar soil. Investigators using lunar soil will need to devise clever ways to make measurements on very small samples. As an example, planetary geologists typically measure major element composition for rare samples on 50 milligrams of material. Efficient use of lunar soil to determine a wide range of physical properties may lie in making a large (about 1 kilogram), homogeneous sample pool from less scientifically valuable lunar fines. Investigations in one property, say interparticle friction, will have benefit of previously determined properties like grain size and shape. Yet, sub-pools of specialty soils may be needed to determine some properties such as solubility in fused salts or a wetability. A list of physical properties, deemed necessary to know for lunar base planning, should suggest what kind of sub-pools would be most helpful. Mature mare (Fe, Ti, H, C, N, glass enriched) and highlands (Ca, Al enriched) sub-pools seem likely candidates. These soil-types were chosen from the broad classification given below. Chemical enrichments, shown below for some important classes, illustrate differences among lunar soils. Maturity classification is from (1) and chemical data from (2).

SOIL CLASSIFICATION

Total Mare:	Apollo 11, 12 soils Apollo 15, 17 soils with FeO > 14%
High Titanium Mare:	Apollo 11 soils Apollo 17 mare soils
Low Titanium Mare:	Apollo 12 soils Apollo 15 mare soils
Highlands:	Apollo 16 soils
K,P enriched:	Apollo 14 soils
Mature vs. Immature:	Ratio of fine-grained metallic iron to total iron content

EXAMPLE OF INTERMEDIATE CHEMISTRY

Apollo 14	O = 44%	Si = 22%	Fe = 10%
	Al = 9%	Mg = 8%	Ca = 6%

CHEMICAL ENRICHMENTS

Mare: Fe = 14% Ti = 5% Mn =0.17% Cr =0.2%

Highlands: Ca = 14% Al = 11%

K, P enriched: K =0.5% P =0.2%

Mature: H = 100 ppm C = 100 ppm N = 100 ppm

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FRACTIONAL DISTILLATION IN A REDUCED GRAVITY AND PRESSURE ENVIRONMENT

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The establishment of a permanent lunar base will undoubtedly employ distillation operations as a routine practice in order to maintain the existence of the base. Fractional distillation will be important in cryogenic separation of gases, reclamation of liquids, production of fuels and many other chemical refining processes. While distillation on Earth is a mature field, there will be some needed design modifications including some pleasant advantages encountered with the low gravity, low pressure lunar environment. Column flooding, pressure drop and plate efficiencies will be affected as will heat exchanger design. Thermal lagging will be facilitated by the lunar atmosphere as well as low pressure "Vacuum" distillation. The details of individual plate or packing design will need to be optimized for best overall separation efficiency. The resulting distillation equipment for lunar operation will reflect these obvious changes, along with many subtle improvements that are yet unconceived until attempted.

Microwave Processing of Lunar Materials: Potential Applications

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The microwave processing of lunar materials to produce either oxygen, primary metals, or ceramic materials is discussed. Extra high frequency microwaves (EHF) at between 100 and 500 gigahertz have the potential for selective coupling to specific atomic species and concomitant low energy requirement for the extraction of specific materials, such as oxygen, from lunar ores. If water bearing lunar materials are found, as for example in permanently shadowed polar regions, the selective coupling of lower (2.45 GHz) microwaves to this water might enable it to be efficiently extracted. Microwave melting and the preparation of these materials for subsequent electrochemical processing or for the preparation of simplified geometries (e.g., bricks) with custom-tailored microstructures.

The principles of the microwave processing of ceramics and minerals are discussed, and the possibility is explored of exploiting the presence of large numbers of fossil cosmic particle induced defects in lunar materials to achieve improved microwave coupling compared to that obtainable with similar terrestrial materials.

Experimental results of the microwave melting of mixed ilmenite, alkali basalt, and ilmenite basalt mixtures as well as TiO_2 doped α-Fe_2O_3 are presented.

Machining in Micro-g

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A machine tool brought to orbit would not retain its accuracy, and its operation could damage the vehicle which carries it.

Machine tools design must provide acceptable accuracy and cutting force, and access to the workpiece by the operator. Further, the intrinsic bulk of conventional AC electric motors forces the designer to locate them at some distance from the cutting load. Machine tools tend to have torque box frames, with the workpiece mounted overhead (Fig. 1), giving the operator 270 degrees or so of access to the workpiece. The cutter must be cantilevered to the frame (Fig. 2), and the workpiece must also be cantilevered (Fig. 3). The cutting forces form a torque, which deforms the frame (Fig. 4). Since cutting forces are time varying and large, resonance can store significant energy in the frame.

Machine tools for use on land rely on their foundation to add rigidity and dissipate vibrational energy. Those for use on ships must be "caged" or otherwise specially designed, as shipboard foundations cannot usually either provide rigidity or dissipate energy. These shipboard tools are usually of lesser capability than land machine tools.

Machine tools in micro-g environments face problems similar to those of a shipboard environment, but more severe. The space installation itself cannot easily provide rigidity, nor can it easily dissipate vibrational energy. Machine tool design for micro-g environments must take this into account in addition to the more commonly described problems of chip and lubricant handling.

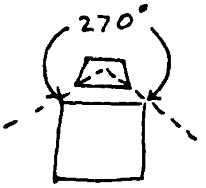

Fig. 1

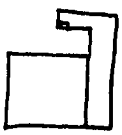

Fig. 2

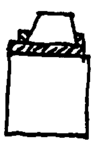

Fig. 3

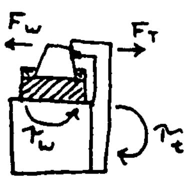

Fig. 4

THE INITIAL LUNAR BASE AND ITS GROWTH POTENTIAL

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ABSTRACT

The decisions made early in the development of a lunar base should be such that future growth potential is facilitated rather than encumbered. This paper will focus on the development of the initial lunar base and demonstrate how it can grow to support several long range objectives.

The proposed approach will begin with an assumption of the technology and space transportation infrastructure expected to be available in the year 2000. These assumptions will include a growth Space Station with servicing for an H_2-0_2 cryogen fueled, high performance space-based orbit transfer vehicle and heavy lift earth-to-orbit launch vehicles. Then several options for growth will be presented in logical phased steps with an objective of striving towards self-sufficiency. Impacts to earth support and the Space Station will be discussed.

LUNAR MISSION MODES

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ABSTRACT NOT RECEIVED IN TIME FOR INCLUSION

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